HELENA VALLEY, MONTANA, AREA ENVIRONMENTAL POLLUTION STUDY

ENVIRONMENTAL PROTECTION AGENCY
Office of Air Programs
Research Triangle Park, North Carolina
January 1972

The AP series of reports is issued by the Environmental Protection Agency to report the results of scientific and engineering studies, and information of general interest in the field of air pollution. Information presented in this series includes coverage of intramural activities involving air pollution research and control technology and of cooperative programs and studies conducted in conjunction with state and local agencies, research institutes, and industrial organizations. Copies of AP reports are available free of charge – as supplies permit – from the Office of Technical Information and Publications, Office of Air Programs, Environmental Protection Agency, Research Triangle Park, North Carolina 27711

Office of Air Programs Publication No. AP- 91

PREFACE

The Helena Valley, Montana, Area Environmental Study was conducted cooperatively, from June 1969 through June 1970, by the Federal Government and the State of Montana.

Because it had been alleged that pollutants are contributing to the endangerment of health and welfare in the Helena Valley, this study was undertaken to provide factual information bearing on the allegations and to aid in delineating the solution of any observed problem.

The investigation concerned contamination of the environment by arsenic, cadmium, lead, zinc, and sulfur dioxide from the industrial smelting complex in the city of East Helena.

Since the atmosphere was suspected as being the major pollutant-transport mechanism in the area's environment, the National Air Pollution Control Administration* was designated to lead and coordinate Federal participation in the study.

The study included the investigation of in-plant air quality and lead accumulation in smelter workers. However, since right-of-entry to the plants was gained under Montana State law, which prohibits publication or public release of any information gathered during in-plant surveys, such material is not included in this report. Results were furnished to the Montana State Department of Health for such use as it may deem appropriate.

---

*Presently the Office of Air Programs of the Environmental Protection Agency.

ACKNOWLEDGMENTS

Mr. Benjamin F. Wake, Director, Division of Air Pollution, State Department of Health, and Mr. Earl V. Porter, Director, Region VIII, Office of Air Programs, Environmental Protection Agency, served as the respective State and Federal Co-Directors of the study.

Mr. Norman A. Huey, Assistant Director, Region VIII, Office of Air Programs, Environmental Protection Agency, was principal technical coordinator and compiler of the study.

Mr. William H. Megonnell, Compliance Officer, Office of Air Programs, Environmental Protection Agency, assisted with the overall study direction and report preparation.

BIBLIOGRAPHIC DATA SHEET

1. Report No. AP-91

2.

3. Recipient's Accession No.

4. Title and Subtitle
Helena Valley, Montana, Area Environmental Pollution Study

5. Report Date January 1972

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
ENVIRONMENTAL PROTECTION AGENCY
Office of Air Programs
Research Triangle Park, North Carolina

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address
Same

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts

The types, amounts, sources, distribution, and effects of pollution were studied. Air, water, and soil were examined for contamination by arsenic, cadmium, lead, and zinc. In addition, airborne sulfur dioxide was measured. All measurements were made between June 1969, and June 1970. The investigation concerned contamination of the environment from the industrial smelting complex in the city of East Helena. Atmospheric concentrations of sulfur dioxide in the Helena Valley exceed Montana air quality standards and levels reported in Federal criteria to be associated with deleterious effects on human health, vegetation & materials. Industrial operations in East Helena are the responsible sources. Air, water, and soil are contaminated with heavy metals from the East Helena smelting complex. Arsenic, cadmium, and lead, which are emitted as air pollutants from both plants, settle and accumulate in soil and on vegetation to an extent surpassing levels that are toxic to grazing farm animals. Furthermore, evidence indicates that sub-clinical effects could be occurring in humans.

17. Key Words and Document Analysis. 17a. Descriptors

Air pollution
Environmental surveys
Exhaust emissions
Water pollution
Soils
Arsenic inorganic compounds
Cadmium inorganic compounds
Lead inorganic compounds
Zinc inorganic compounds
Sulfur dioxide
Metal industries
Industrial wastes
Health
Plants (botany)
Animals
Farms
Hair
Vegetables
Ingestion (biology)
Meteorology

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 13B

18. Availability Statement
Unlimited

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages 194

22. Price

FORM NTIS-35 (10-70)

USCOMM-DC 40329-P71

LIST OF FIGURES

Figure *Page*

2-1 Sulfur Dioxide Monitoring Locations 26
2-2 SO_2 Frequency Distribution at Sampling Location 1 29
2-3 SO_2 Frequency Distribution at Sampling Location 2 30
2-4 SO_2 Frequency Distribution at Sampling Location 3 31
2-5 SO_2 Frequency Distribution at Sampling Location 4 32
2-6 SO_2 Frequency Distribution at Sampling Location 5 33
2-7 Annual Average Spatial Distribution of SO_2, June 1969 through May 1970 34
2-8 Study Period Spatial Distribution of SO_2, July through October 1969 35
2-9 Spatial Distribution of SO_2 During Partial Plant Shutdown, June 1969 36
2-10 Spatial Distribution of SO_2, July 1969 37
2-11 Spatial Distribution of SO_2, August 1969 38
2-12 Spatial Distribution of SO_2, September 1969 39
2-13 Spatial Distribution of SO_2, October 1969 40
2-14 Spatial Distribution of SO_2, November 1969 (1 Month After End of Study Period) 41
2-15 Winter Spatial Distribution of SO_2, December 1969 through February 1970 42
2-16 Spatial Distribution of SO_2, March through May 1970 43
2-17 Sulfur Dioxide Trend from July 1968 to November 1969 45
2-18 Settleable Particulate Arsenic Radial Distribution 52
2-19 Settleable Particulate Cadmium Radial Distribution 54
2-20 Settleable Particulate Lead Radial Distribution 56
2-21 Settleable Particulate Zinc Radial Distribution 59
4-1 Sampling Locations 67
5-1 Control and Exposed Plant Sites at Station 1 82
5-2 Locations of Greenhouses and Experimental Gardens in the East Helena Study 83
5-3 Average Heavy-Metal Levels in Plants Grown in Experimental Gardens Around East Helena in 1969 86
5-4 Heavy-Metal Content of Soils in Experimental Gardens Around East Helena in 1969 87
5-5 Sulfur Dioxide Leaf Injury to Alfalfa at Station 3 93
6-1 Animal Collection Sites 96
6-2 Plant Collection Sites 102
10-1 Simplified Flow Diagram for Lead Plant 148

10-2 Simplified Flow Diagram for Slag-Processing Plant 155
10-3 Simplified Flow Diagram for Pigment Plant 159
11-1 Annual Wind Rose, Helena, Montana 162
11-2 Temperature Soundings on Day with Clear Skies and Light Winds.. 164
11-3 Typical High-Level Temperature Soundings, Summer and Winter .. 165
11-4 Graphical Determination of Afternoon (Maximum) Mixing Depth.. 168
11-5 Estimated Mean Concentrations of SO_2 (ppm) from Three Sources in Helena Valley, June through October 1969 173
11-6 Estimated Mean Annual Concentrations of SO_2 (ppm) from Three Sources in Helena Valley. (No Fan or Heater on Stack) 175
11-7 Estimated Mean Annual Concentrations of SO_2 (ppm) from Three Sources in Helena Valley 176
11-8 Estimated Mean Annual Concentrations of SO_2 (ppm) from ASARCO Stack with Fan and Heater 177

LIST OF TABLES

Table *Page*

1-1 Estimated Population of Helena and East Helena 6
1-2 Helena Valley Property Evaluation 8
1-3 Heavy-Metal Levels in Hair for Three Cities 19
2-1 Number of Occurrences and Length of Time Specific Levels Exceeded 27
2-2 Comparison of Sulfation Predictions with Measured ppm Values . . 44
2-3 Particulate Sulfate Summary Statistics 46
2-4 Particulate Acidity Summary Statistics 47
2-5 Total Suspended Particulate Summary Statistics 48
2-6 Settleable Particulate Results 49
2-7 Soiling Index Summary Statistics, June Through October 1969 . . . 49
2-8 Particulate Arsenic Summary 50
2-9 Particulate Cadmium Summary 53
2-10 Particulate Lead Summary 55
2-11 Particulate Zinc Summary 58
3-1 Water Quality Analytical Results 63
4-1 Instrumental Parameters for Determining Lead and Zinc Content of Soil 69
4-2 Estimates of Experimental Error 70
4-3 Estimated Relative Importances of Errors in Sampling and Laboratory Analysis 71
4-4 Soil Metal Content as Function of Distance from Smelter 72
4-5 Expected Lead, Zinc, Cadmium, and Arsenic Contents of Cultivated Soils Along Traverses A, B, and C 73
4-6 Expected Lead, Zinc, Cadmium, and Arsenic Contents of Uncultivated Soils Along Traverse D 74
5-1 Heavy-Metal Content of Vermiculite and Soils Used in Greenhouses and Experimental Gardens 84
5-2 Average Heavy-Metal Content of Experimental Vegetation 85
5-3 Ranges of Heavy Metals in Plants Sampled from Residential Gardens and Ranches in East Helena Area 89
5-4 Ranges of Heavy Metals in Garden Plants, Small Grains, Alfalfa, and Pasture Grasses Sampled in East Helena Area in 1969 90
5-5 Injury Found on Indigenous Vegetation 91
5-6 Type and Extent of Leaf Damage on Experimental Vegetation 92
5-7 Growth Suppression of Experimental Vegetation 93
6-1 Lead and Cadmium in Animal Tissues 97
6-2 Accounts of Species Taken in East Helena Area, Summer 1969 . . . 99

6-3 Lead and Cadmium Concentrations of Soil, Grass, and Rodent Tissues 101
6-4 Lead and Cadmium Content of Soil and Lettuce 103
6-5 Comparison of Washed with Unwashed Lettuce from the Same or Neighboring Gardens 104
6-6 Heavy-Metal Content of Lettuce Grown in East Helena and in East Helena Soil Transported to Missoula 104
6-7 Lead and Cadmium Contents of Rabbit Tissues 106
6-8 Lead and Total Sulfur in Conifer Foliage in East Helena, 1969 108
7-1 Collection Sites for Horse-Mane Samples 115
7-2 Analyses for Arsenic, Zinc, Cadmium, and Lead in Horse-Mane Hair 116
7-3 Ranking of Sites by Average Metal Content of Horse Mane 119
7-4 Field Notes on Horses Sampled 120
7-5 Postmortem Organ Analyses of Horse, Site 2 122
7-6 Selected Metal Contents of Miscellaneous Animal Products 124
8-1 Distribution of Arithmetic Mean Hair Lead Levels by City 126
8-2 Distribution of Arithmetic Mean Hair Cadmium Levels by City . . . 127
8-3 Distribution of Arithmetic Mean Hair Arsenic Levels by City 127
8-4 Distribution of Arithmetic Mean Hair Zinc Levels by City 128
8-5 Distribution of Arithmetic Mean Hair Copper Levels by City 128
8-6 Distribution of Hair Lead Levels by City 129
8-7 Distribution of Hair Cadmium Levels by City 129
8-8 Distribution of Hair Arsenic Levels by City 130
8-9 Distribution of Hair Zinc Levels by City 130
8-10 Distribution of Hair Copper Levels by City 131
8-11 Summary of Arithmetic Mean Concentrations of Trace Metals in East Helena, Helena, and Bozeman, Montana 131
8-12 F Ratios of Trace-Metal Concentrations in East Helena, Helena, and Bozeman, Montana 132
9-1 Estimated Zinc Balance in Man 135
9-2 Estimated Cadmium Balance in Man 136
9-3 Estimated Arsenic Balance in Man 137
9-4 Estimated Lead Balance in Man 138
9-5 Estimated Daily Consumption of Garden Vegetables and Fruits . . . 139
9-6 Estimated Total Daily Intake of Arsenic, Cadmium, Lead, and Zinc from Diet, Water, and Air 140
9-7 Estimated Daily Intake of Arsenic, Cadmium, Lead, and Zinc from the Diet 141
10-1 1968 Emissions in Helena Valley, Montana, Area 145
10-2 Emissions from East Helena Industrial Complex 147
11-1 Monthly Mean Windspeeds, Helena, Montana, 1937 to 1963 163
11-2 Seasonal and Annual Inversion Frequency at Helena, Montana 166
11-3 Seasonal and Annual Inversion Frequency at Idaho Falls, Idaho . . . 166
11-4 Stability in Helena Valley 167

11-5 Normal and Actual Monthly Windspeed, Precipitation Amounts, and Number of Days with Precipitation, Helena, Montana 169
11-6 Three Most Significant Sulfur Dioxide Sources 169
11-7 Short-Term Concentrations of SO_2 at East Helena Park 170
11-8 Estimated Maximum Ground-Level Centerline Concentrations of SO_2 and Distance from Source for Selected Meteorological Conditions 171
11-9 Concentrations of SO_2 at East Helena Park During Aerodynamic Downwash from Source Buildings, Windspeed of 8 mph 172

CONTENTS

1. SUMMARY 1
RESULTS AND RECOMMENDATIONS 1
INTRODUCTION 2
  Background Information 4
  Review of Previous Pollution Studies 7
ENVIRONMENTAL EVALUATION 9
  Sulfur Dioxide 9
  Arsenic 11
  Cadmium 12
  Lead 13
  Zinc 14
EVALUATION OF POLLUTANT EFFECTS 15
  Vegetation 15
  Animals 17
  Humans 18
POLLUTANT SOURCES 19
  Sulfur Dioxide Emissions 20
  Particulate Emissions 22
  Waste Water Emissions 23
  Solid Waste Disposal 23
2. SURVEY OF AIRBORNE POLLUTANTS 25
INTRODUCTION 25
SULFUR DIOXIDE 25
  Point Measurements of Sulfur Dioxide 25
  Spatial Distribution of Sulfur Dioxide 28
  Long-Term Trends 44
  Sulfur Dioxide Related Measurements 44
NONSPECIFIC PARTICULATES 47
  Total Suspended Particulates 47
  Settleable Particulates 47
  Windblown Particulates 49
  Soiling Index 49
METALLIC PARTICULATES 50
  Arsenic 50
  Cadmium 53
  Lead 55
  Zinc 57
OZONE AND NITROGEN DIOXIDE 58
  Ozone 58
  Nitrogen Dioxide 60

Preceding page blank

REFERENCES FOR CHAPTER 2 60

3. SURVEY OF WATER QUALITY 61
 - INTRODUCTION 61
 - TYPES OF WATER SUPPLIES 61
 - SAMPLING 61
 - LABORATORY METHODS 62
 - RESULTS 62
 - DISCUSSION OF RESULTS 62
 - SUMMARY 63

4. ABUNDANCE AND DISTRIBUTION OF LEAD, ZINC, CADMIUM, AND ARSENIC IN SOILS 65
 - INTRODUCTION 65
 - CHARACTER OF SOILS 65
 - SAMPLING 65
 - LABORATORY METHODS 68
   - Evaluation of Errors Due to Sampling and Laboratory Analysis 70
 - DISCUSSION OF RESULTS 71
   - Lead 74
   - Zinc 75
   - Cadmium 76
   - Arsenic 77
   - Other Elements 77
 - SUMMARY AND CONCLUSIONS 78
 - REFERENCES FOR CHAPTER 4 80

5. SOIL AND VEGETATION STUDY 81
 - INTRODUCTION 81
 - ORIGIN OF HEAVY METALS IN VEGETATION 81
   - Methods and Materials 81
   - Results and Discussion 84
 - SUMMARY 88
 - AMOUNT OF HEAVY METALS IN SOILS AND VEGETATION 88
   - Methods and Materials 88
   - Results and Discussion of Soil Analyses 88
   - Results and Discussion of Vegetation Analyses 89
 - SUMMARY 90
 - VISIBLE PLANT DAMAGE TO INDIGENOUS AND GREENHOUSE VEGETATION 90
   - Methods and Materials 90
   - Results and Discussion 91
 - SUMMARY 94

6. EFFECTS OF AIR POLLUTION ON INDIGENOUS ANIMALS AND VEGETATION 95
 - INTRODUCTION 95
 - ACCUMULATION OF LEAD AND CADMIUM IN INDIGENOUS ANIMALS 95
 - LEAD AND CADMIUM IN GARDEN VEGETABLES 102

Source of Lead and Cadmium in Garden Vegetables 104
UPTAKE OF CADMIUM AND LEAD FROM FOOD SOURCES 104
CONIFER FOLIAGE INVESTIGATIONS 107
Sulfur and Lead Content 107
Histological Examinations 109
BIBLIOGRAPHY FOR CHAPTER 6 110
7. EFFECTS OF AIR POLLUTION ON LIVESTOCK AND ANIMAL PRODUCTS 113
EFFECTS ON LIVESTOCK 113
Methods 113
Results 115
Conclusions 122
CONTAMINATION OF LIVESTOCK PRODUCTS 123
8. TRACE-METAL CONCENTRATIONS IN HUMAN HAIR 125
BACKGROUND AND INTRODUCTION 125
MATERIALS AND METHODS 125
RESULTS 126
DISCUSSION 132
SUMMARY 133
REFERENCES FOR CHAPTER 8 133
9. POSSIBLE HAZARDS ASSOCIATED WITH INGESTION OF GARDEN VEGETABLES CONTAMINATED BY TRACE METALS 135
INTRODUCTION 135
ZINC METABOLISM 135
Balance 135
Toxicity 136
CADMIUM METABOLISM 136
Balance 136
Toxicity 136
ARSENIC METABOLISM 137
Balance 137
Toxicity 137
LEAD METABOLISM 138
Balance 138
Toxicity 138
DAILY CONSUMPTION OF GARDEN VEGETABLES AND FRUITS 138
ESTIMATED DIETARY LEVELS OF ARSENIC, CADMIUM, LEAD, AND ZINC 139
SIGNIFICANCE OF DATA 140
SUMMARY 142
REFERENCES FOR CHAPTER 9 143
10. POLLUTION SOURCES 145
INTRODUCTION 145
Emission Summary for Helena Valley 145
East Helena Industrial Complex 146

LEAD SMELTING–AMERICAN SMELTING AND REFINING COMPANY 146
  Process Description 146
  Emissions 149
  Air Pollution Control 151
SLAG PROCESSING–ANACONDA COMPANY 153
  Process Description 153
  Emissions 154
  Air Pollution Control 156
PAINT PIGMENT PRODUCTION–AMERICAN CHEMET CORPORATION 158
  Process Description 158
  Emissions and Air Pollution Control 158
11. METEOROLOGY AND SOURCE-RECEPTOR RELATIONSHIPS 161
AIR MOVEMENT 161
  Wind Stations 161
  Wind Direction 162
  Wind Speed 163
ATMOSPHERIC STABILITY AND TEMPERATURE INVERSIONS 163
POTENTIAL AIR POLLUTION EPISODE DAYS 167
PRECIPITATION AMOUNTS AND WIND SPEEDS AFFECTING THE REPRESENTATIVENESS OF THE STUDY PERIOD 168
DIFFUSION ESTIMATES OF MEAN SHORT-TERM SO_2 CONCENTRATIONS 169
DIFFUSION ESTIMATES OF MEAN LONG-TERM SO_2 CONCENTRATIONS 172
DISPERSION OF PARTICULATE MATERIAL 174
SUMMARY 178
REFERENCES FOR CHAPTER 11 179

HELENA VALLEY, MONTANA, AREA ENVIRONMENTAL POLLUTION STUDY

1. SUMMARY

RESULTS AND RECOMMENDATIONS

Atmospheric concentrations of sulfur dioxide in the Helena Valley exceed Montana air quality standards and levels reported in Federal criteria to be associated with deleterious effects on human health, vegetation, and materials. Industrial operations of American Smelting and Refining Company and Anaconda Company in East Helena are the responsible sources.

Air, water, and soil ~~in the~~ Valley are contaminated with heavy metals from the East Helena smelting complex. Water in Prickly Pear Creek is contaminated by the American Smelting and Refining Company plant. Arsenic, cadmium, and lead, which are emitted as air pollutants from both plants, settle and accumulate in soil and on vegetation to an extent surpassing levels that are toxic to grazing farm animals. Furthermore, evidence indicates that subclinical effects could be occurring in humans.

Threshold-limit values have been established for industrial exposure of healthy adults for 8 hours per day, 40 hours per week, during a normal working life; knowledge is insufficient, however, to establish limits below which heavy metals may be considered harmless to humans in various states of health who are exposed to heavy-metal contamination from birth or, through parental contact with heavy metals in the environment, even before birth. Calculations of total body burden of lead and cadmium from air, food, and drink, plus evidence of heavy-metal accumulation in human hair, are sufficient cause for concern and action to control pollution from the smelting complex in East Helena.

Heavy-metal particulates are not prone to significant dispersion, and tall stacks will not change the impact of these particles on the Helena Valley. Increasing the height of emissions is not emission control, in that it removes no pollution; tall stacks merely spread gaseous pollutants and fine particles for wider consumption.

Industrial sources should abate emissions to the lowest practicable levels by application of modern technology.

Residents of Helena Valley should be informed of possible toxic effects from consumption of vegetables or other food items that might be contaminated either from the soil or from dustfall. All locally grown vegetables should be washed to remove surface contamination before consumption.

Ranchers within about 5 miles of the smelting complex should be advised of the danger to low-grazing farm animals like horses and sheep. Such animals should not graze in fields in the vicinity of East Helena.

INTRODUCTION

In 1888 the Helena & Livingston lead smelter was built at East Helena. The American Smelting and Refining Company purchased this operation in 1899. Anaconda Company, in 1927, built a plant adjacent to the lead smelter to recover zinc from the latter's waste slag. In 1955 The American Chemet Corporation constructed a nearby paint pigment plant whose raw material is zinc oxide from the Anaconda zinc plant.

As early as 1901, the American Smelting and Refining Company began protecting itself against claims for damages to the neighboring premises with indentures releasing them from such claims.

Lead contamination of the soil has been acknowledged by the management of American Smelting and Refining Company, as stated by this quotation from a 1963 letter sent to a neighboring rancher by the plant manager:

> I have finally received the results of the soil samples and must report that your soil is highly contaminated with lead. Following are comments on the samples:
>
> Under some circumstances, it is risky to pasture horses on land, the surface portions of the soil of which contain over 200 parts per million of lead. This risk is great when grass is grown in soil with a content of 1000 ppm lead. During the times the grass is lush and the animals can graze in the pasture without cropping low, or without picking up some soil, I should say the danger would be minimized.
>
> I cannot imagine a very luxuriant growth of vegetation in a pasture which contains such high concentrations of metals unless the soil is quite calcareous. Certainly, in this particular area, it would not be "up to the stirrups" of an ordinary size horse. My advice, therefore, is that you discourage the use of this pasture for animals, especially for horses.

Contamination of the air with sulfur dioxide also was acknowledged by letter from management to a neighboring rancher:

> During the spring of 1967 and the spring and summer of 1968, your property south of the smelter has experienced considerable exposure to SO_2. Under the present state of knowledge, it is not likely that the condition can be improved for a matter of years.
>
> Because of this unfortunate situation, it would appear advantageous to all concerned if you were to move out of that location. Possibly you can find another location in the countryside and your house could be moved there.
>
> Please let me know if you are interested so that we can negotiate terms of sale.

An allegation of heavy-metal contamination of garden vegetables was brought to the attention of the Food and Drug Administration's Regional Inspector in Helena on September 20, 1968. This information was relayed from the Food and Drug Administration to the Consumer Protection and Environmental Health Service. Discussions between Montana health officials and the Consumer Protection and Environmental Health Service led to an environmental pollution study of the Helena Valley, Montana, area.

In May 1969, the Memorandum of Agreement that follows was signed by Federal and State officials.

MEMORANDUM OF AGREEMENT
BETWEEN
THE MONTANA STATE DEPARTMENT OF HEALTH
AND
THE NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
THE FOOD AND DRUG ADMINISTRATION
THE ENVIRONMENTAL CONTROL ADMINISTRATION
(CONSUMER PROTECTION AND ENVIRONMENTAL HEALTH SERVICE, PUBLIC HEALTH SERVICE, U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE)

Authority: Under provisions of Section 301 of the Public Health Service Act, as amended (Public Law 78-410), and Section 103 (a) (3) of the Clean Air Act, as amended (Public Law 90-148), the National Air Pollution Control Administration, the Food and Drug Administration, and the Environmental Control Administration of the Consumer Protection and Environmental Health Service, Public Health Service, U. S. Department of Health, Education, and Welfare, and the Montana State Department of Health agree to cooperate in the conduct of a study of environmental pollution as enumerated in the terms of this memorandum.

Title of Project: Helena Valley, Montana, Area Environmental Pollution Study.

Purpose of Project: To conduct a study of the types, amounts, sources, distribution and effects of environmental pollution in the Helena Valley, Montana area, with a view to recommending solutions of any problems that are found.

Need for Project: It has been alleged that pollutants arising from man's activities in the area are contributing to health and welfare endangerment. This study will provide factual information bearing on the allegations and aid in delineating solution of any observed problem.

Location of Project: Helena Valley, Montana; specific geographical boundaries to be determined during field work.

Direction of the Study: Administrative co-direction of the study shall be the responsibility of Mr. Benjamin F. Wake for the State of Montana, and Mr. Earl V. Porter for the Federal government.

Arrangements for and coordination of participation by State and Federal agencies not parties to this agreement shall be the responsibility of the respective co-directors. Technical direction of each party's personnel shall be by the designee of each individual agency.

Duration of Federal Participation: Approximately six months' field work, plus such time as necessary for data analysis and report preparation, unless extension of the study is agreed to by the parties concerned.

Sharing of Data: Data gathered during the study, because of its possible research value, shall be freely acessible to all participating agencies. However, data especially created by the activities of this study, prior to submittal of the final report, shall be released only after consultation with the Montana State Department of Health.

Final Report: A report of findings and recommendations will be prepared by the Federal participants, in consultation with the Montana State Department of Health. Any of the parties to this agreement may disseminate copies of the final report in accordance with their regulations and normal procedures.

Special Provisions: Details concerning conduct of various phases of the study and the roles of individual agency participants will be developed jointly by the Federal and State parties to this agreement and will be appended, as developed, to become parts of this agreement.

Investigations for this study were conducted between July 1969 and July 1970.

Background Information

History

In 1864, four prospectors in the hostile reaches of Montana Territory came upon a gulch that they considered to be their "last chance" in their search for gold. Gold was found in such abundance that a city sprang into existence. Within 1 year this mining community numbered over 100 cabins and was known as "Last Chance." The main street, running north and south through the center of town, became "Last Chance Gulch."

In 1882, shortly after the coming of the railroads, Helena became a corporate city with over 600 citizens voting for a charter.

With the enormous loads of gold being mined in the area, Helena was fast become the banking capital of the territory. The city soon enjoyed the reputation of being the wealthiest city per capita in the world.

When Montana Territory was created by Congress in May 1864, the city of Bannock was the seat of the territory legislature. In 1865, the capital was moved to Virginia City, another booming miners' town 200 miles to the south of Helena. By 1875 Helena was the uncontested center of wealth and culture in the Montana Territory. Shortly thereafter Helena became the capital city.

Prickly Pear Junction, a "way station" on the stage coach route from Ft. Benton to Helena and other gold camps, became East Helena with the building of a lead smelter in 1888. In 1899, the American Smelting and Refining Company purchased the old Helena & Livingston plant. In 1927, the Anaconda Company installed a zinc plant, and other industries that use smelter by-products settled in the vicinity.

Topography

The Helena Valley in western Montana is an intermountain Valley bounded on the north and east by the Big Belt Mountains and on the west and south by the main chain of the Continental Divide. The Valley is approximately 25 miles in width from north to south, and 35 miles long from east to west. The average height of surrounding mountains above the valley floor (elevation 3700 feet) is about 3000 feet.

The city of Helena, with an average elevation of 4100 feet, is located on a slope at the south side of the Valley. The southern parts of the city have elevations of about 4300 feet, and the northern parts are at elevations of about 3800 feet.

The city of East Helena is located about 4 miles east of Helena at an elevation of about 3900 feet. The ground slope is much less evident in East Helena than it is in Helena. The ground south of East Helena, where the smelting operations are located, is 30 to 50 feet higher than the city.

The valley floor continues to slope gently to the north and northeast to Lake Helena, which is located about 10 miles northeast of East Helena. Lake Helena is the lowest point in the Valley with an elevation of 3650 feet.

Climatology

The climate of the Helena Valley may be described as modified continental.

As may be expected in a northern latitude, cold waves may occur from November through February, with temperatures occasionally dropping well below zero. Summertime temperatures are moderate, with maximum readings generally under 90° F and very seldom reaching 100°.

Total precipitation varies widely throughout the Valley, from a semiarid total of 9 to 10 inches in the drier northern and eastern portions of the Valley, to a subhumid 30 inches along the Continental Divide to the southwest. Most of the precipitation falls from April through July from frequent showers or thundershowers, with some steady rains in June, the wettest month of the year. Late summer, fall, and winter months are relatively dry. Snow can be expected from September through May. During the winter months snow may remain on the ground for several weeks at a time. Amounts during the spring and fall are usually light.

Strong and persistent temperature inversions are common to the Helena Valley. The surrounding mountains shelter the area from the winds. At night, cold air drains into the Valley from the surrounding mountain slopes.

Population Statistics

Population statistics for the Helena Valley can be estimated from Helena and East Helena statistics. There are 125 farms in the Valley. These people may not be included in the city statistics. Table 1-1 gives population estimates for Helena and East Helena.

Table 1-1. ESTIMATED POPULATION OF HELENA AND EAST HELENA

Year	Helena	East Helena
1950	17,581	1,216
1960	20,227	1,490
1969	26,602	2,079

Employment

The largest employer in the Helena Valley is the State of Montana. Helena is the state capital. Retail trade and professional services make the greatest remaining contribution to employment.

Industry

Heavy industrial manufacturing companies have located within the city of East Helena. American Smelting and Refining Company operates a custom lead smelter that employs 180 workers. Anaconda Company operates a zinc recovery plant that employs 80 workers. American Chemet manufactures paint pigments and employs 10 people. Several miles southwest of the city of East Helena, the Kaiser Cement and Gypsum Company operates a cement plant that employs 75 workers.

About 20 light industrial manufacturing companies in the city of Helena employ about 400 people.

Agricultural Activity

There are approximately 220,000 acres of agricultural land on the valley floor, valued at about $10 million.

Most farming in the Valley is by dry-land practices. The soil is seeded 1 year, left fallow the next, and seeded again the third year. A total of 20,000 acres of wheat and barley is planted each year. The yearly gross income is estimated to be $300,000 and $200,000 from wheat and barley, respectively. Four thousand acres of alfalfa is grown on irrigated land with the estimated worth being about $2 million. Two hundred acres is planted in either corn, oats, or potatoes, with an approximate value of $9,000. Three thousand acres is used as seeded or improved pasture, and about 200,000 acres is used as range-land pasture.

About 700 private gardens are planted in the Valley to produce tomatoes, beets, carrots, corn, beans, peas, onions, radishes, and cabbage.

There are 15,000 cows and calves in the Valley; their market value is $3 million. Also present are 5,000 sheep and lambs, 5,000 chickens, 1,000 hogs, and 800 horses, the combined worth of which is estimated at more than $300,000.

Property Evaluation

Value of properties within the Helena Valley, estimated from the biennial reports of the State Board of Equalization for Lewis and Clark County, is shown in Table 1-2.

Review of Previous Pollution Studies

A Study of Air Pollution in Montana, July 1961 to July 1962

There was a study of air pollution conducted by the Montana State Board of Health from July 1961 to July 1962 with assistance from the Division of Air Pollution, Public Health Service, U.S. Department of Health, Education, and Welfare. Limited air quality measurements were made in seven Montana cities.

Total suspended particulate loadings in the city of Helena were reported to

Table 1-2. HELENA VALLEY PROPERTY EVALUATION
(dollars)

Lewis and Clark County	June 30, 1960	June 30,1968
Assessed valuation	80,000,000	100,000,000
Personal property	30,000,000	30,000,000
All real estate, including improvements, town lots	40,000,000	60,000,000
Agricultural lands and improvements	6,000,000	7,000,000
Grazing lands	3,000,000	3,000,000
All livestock	2,000,000	3,000,000
All timber	70,000	80,000

average 72 micrograms per cubic meter ($\mu g/m^3$) of air. Arsenic, lead, and fluoride were reported to average 0.08, 0.34, and 0.10 $\mu g/m^3$, respectively.

A Study of Air Pollution in the Helena - East Helena Area, October 1965 to October 1968

Another study of air pollution, from October 1965 to October 1968, was conducted by the Montana State Department of Health. The objective was to define the quantity and quality of certain air pollutants in the Helena - East Helena area.

Monthly average sulfur dioxide (SO_2) concentrations up to 0.055 part per million (ppm), hourly averages up to 0.4 ppm, and 5-minute average concentrations up to 6 ppm were reported. Suspended particulate loadings averaged 76 $\mu g/m^3$ in East Helena and 50 to 60 $\mu g/m^3$ at various sampling locations in Helena. Arsenic and lead concentrations were higher in East Helena than in Helena. The contribution of the smelter complex in East Helena to air pollution was demonstrated by the decline in sulfation, dustfall, and lead content of dustfall during a smelter strike.

The study recommendations called for reduction in sulfur dioxide and dust emissions from the East Helena smelting complex, prohibition of open burning, and elimination of street dust through paving.

Pollution Study in East Helena, December 1968

In December 1968, a study of pollution in East Helena, financed by the Montana State Board of Health, was conducted by Dr. C. C. Gordon, Associate Professor of Botany, University of Montana, Missoula, Montana. The study objective was to determine the severity and extent of sulfur dioxide damage to vegetation. The study scope was extended to include an investigation of the effects of lead and cadmium on the ecosystem.

Dr. Gordon reported that local farmers had stated that raising of horses had not been feasible for several decades. American Smelting and Refining Company plant management reportedly has been of the opinion that residents of East Helena should not eat local garden vegetables because of metal contamination.

Sulfur dioxide effects were found on pine seedlings as far as 4 miles south of the East Helena smelter complex. Elevated lead and cadmium levels were reported in garden vegetables and in animal tissues.

ENVIRONMENTAL EVALUATION

Air, water, and soil were examined for contamination by arsenic, cadmium, lead, and zinc. In addition, airborne sulfur dioxide was measured.

Sulfur Dioxide

Sample averaging time is important in the evaluation of sulfur dioxide pollution of the air. Unlike generalized air quality deterioration from myriad emission sources in urban areas, a single source or a few sources in close proximity will cause a heterogeneous pollutant distribution usually characterized by infrequent but severe levels. The Helena Valley is subjected to this type of pollutant distribution, as demonstrated by the range in annual, daily, hourly, and 1-minute average sulfur dioxide concentrations.

Annual Mean Concentrations

The Environmental Protection Agency's Office of Air Program's best judgment of effects that occur when various levels of pollution are reached is reported in AP-50, *Air Quality Criteria for Sulfur Oxides*. This document states that:

1. At concentrations of 0.04 ppm, frequency of lung disease may increase and mortality from bronchitis and lung cancer may occur.

2. At concentrations of 0.03 ppm, chronic plant injury and excessive leaf drop may occur.

3. At concentrations of 0.12 ppm, the corrosion rate of steel may increase by 50 percent.

The Montana State Board of Health adopted 0.02 ppm sulfur dioxide maximum annual average as a statewide ambient air quality standard on May 27, 1967.

The city of Helena experienced 0.01 ppm from June 1969 to June 1970. Residents of East Helena were exposed to 0.01 to 0.08 ppm, depending upon their location within the city. Throughout most of East Helena, levels varied between 0.02 and 0.04 ppm, but a small center-city portion was exposed to levels between 0.04 and 0.08 ppm. A 20-square-mile area adjacent to and southeast of the city of East Helena had levels greater than 0.02 but less than 0.04 ppm. The remainder of the Helena Valley was not exposed to levels greater than the State standard of 0.02 ppm.

Daily Concentrations

Air Quality Criteria for Sulfur Oxides states that:

1. At concentrations of 0.1 ppm, absenteeism from work and increased hospital admissions of older persons for respiratory disease may occur.

2. At concentrations of 0.2 to 0.3 ppm, patients with chronic lung disease may experience accentuations of symptoms, and the general population may experience increased mortality.

Montana's statewide sulfur dioxide standard is 0.10 ppm, 24-hour average, not to be exceeded over 1 percent of the days in any 3-month period.

The concentration equaled or exceeded 0.1 ppm on 4 of the 129 days sampled (3 percent) in Helena, on 5 of the 128 days sampled (4 percent) in East Helena, on 15 of the 136 days sampled (11 percent) in the Helena Valley 0.5 mile southeast of the smelter, and on 10 of the 123 days sampled (8 percent) in the Helena Valley 2.5 miles southeast of the smelter.

Concentrations equaled or exceeded 0.2 ppm on 4 days 0.5 mile southeast of the smelter and on 1 day at 2.5 miles southeast.

Hourly Concentrations

Air Quality Criteria for Sulfur Oxides reveals that at concentrations of 0.10 ppm sulfur dioxide, in the presence of particulates, visibility may be reduced to about 5 miles.

Montana's standard is 0.25 ppm, not to be exceeded more than 1 hour in any 4 consecutive days. In approximately 140 days of sampling in the summer of 1969, 0.25 ppm was exceeded during 41 hours in Helena, 47 hours in East Helena, 126 hours in the Helena Valley 0.5 mile southeast of the smelter complex, and 74 hours in the Helena Valley 2.5 miles southeast of the smelter complex.

Maximum Concentrations

While the effects of short-term peak concentrations are not discussed in the Air Quality Criteria Document and although limits are not included in the Montana State standards, at concentrations greater than 1 ppm the air usually is so fouled as to cause nausea and coughing in the normal population. The taste threshold occurs at 0.3 ppm.

The instruments used during the 140-day sampling period to measure sulfur dioxide had an upper limit of detection of 4 ppm. The monitor located in Helena registered greater than 1 but less than 2 ppm for 48 minutes. The monitor in the city of East Helena registered greater than 2 but less than 4 ppm for a total of 41 minutes. In the Valley 0.5 mile southeast of the smelter, a monitor registered greater than 4 ppm for about 2 minutes.

Arsenic

Arsenic compounds are toxic to humans, animals, and plants. Most arsenic compounds, when heated in air, are converted to arsenic trioxide, a tasteless, toxic, white powder. Arsenical dusts can produce dermatitis, bronchitis, and irritation to the upper respiratory tract. Ingestion of arsenic can produce keratosis and cancer of the skin. The relationship of arsenic to other types of cancer, particularly lung tumors, is strongly suggestive. Herbivorous animals have been poisoned from eating plants contaminated with arsenic. Seventy milligrams of arsenic trioxide has been reported as a fatal dose for man.

Contamination of Air

Maximum permissible atmospheric concentrations have not been adopted in the United States. A 24-hour standard of 3 $\mu g/m^3$ has been recommended in the U.S.S.R. and Czechoslovakia.

During the summer and fall of 1969, an average 24-hour concentration of 0.005 $\mu g/m^3$ was found in Helena. Maximum 24-hour concentrations did not exceed 0.07 $\mu g/m^3$. East Helena was exposed to an average of 0.08, although the maximum reached 0.3 $\mu g/m^3$. These values represent the highest found in the Helena Valley.

The concentration of arsenic in the particulates that settle in the vicinity of the East Helena smelter is 200 to 1000 ppm. Each month, 1 to 4 milligrams (mg) of arsenic settle on each square meter of surface area within a 1-mile radius of the smelter.

Contamination of Water

Arsenic concentrations of 2 to 4 mg per liter are reported not to interfere with the self-purification of streams. The Montana water quality criteria are consistent with the Public Health Service Drinking Water Standards that state that the concentration of arsenic in drinking water should not exceed 0.01 mg per liter and concentrations in excess of 0.05 mg per liter are grounds for rejection of the supply.

Sampling of waters in the Helena Valley revealed arsenic in the surface waters in Prickly Pear Creek, downstream from the smelting complex. On October 25, 1969, and on April 4, 1970, the surface water in Prickly Pear Creek, which is 2.5 miles northwest of East Helena, contained 0.01 mg per liter. On the same dates, Missouri River water at the Helena City Water Plant intake contained 0.02 mg per liter.

Contamination of Soil

The arsenic content of soils ranges from 1 to 50 ppm and averages about 5 ppm. The soil outside, but adjacent to, the Helena Valley contains 6 ppm.

The concentrations of arsenic in the soil decrease with distance from the smelting complex. At distances of 1 and 2 miles, respectively, the upper inch of uncultivated soil contains 140 and 23 ppm and the upper 4-inch layer of cultivated soil contains 40 and 20 ppm.

Cadmium

Cadmium is recognized as an element with high toxic potential. Children have been made sick by consuming a frozen dessert containing 13 to 15 mg of cadmium per liter.

Cadmium is absorbed without regard to the level of existing body concentrations, which indicates a lack of homeostatic mechanisms for the control of cadmium levels. It has been reported that the feeding of 0.1 mg of cadmium per liter causes accumulation of cadmium in the liver and kidney tissues of rats.

Epidemiological evidence associating cadmium with renal arterial hypertension in humans is conflicting.

Contamination of Air

When inhaled, cadmium can produce pulmonary emphysema and bronchitis, kidney damage resulting in proteinuria, and gastric and intestinal disorders. In one epidemiological study, air cadmium levels have been associated with cardiovascular mortality rates, but this relationship is very tenuous and has not been confirmed in other studies to date.

Maximum permissible atmospheric concentrations for cadmium have not been suggested or adopted in the United States. In 1963, the National Air Sampling Network reported that the nation's air contained an average 24-hour concentration of 0.002 $\mu g/m^3$.

The maximum reported individual annual concentration was 0.028 $\mu g/m^3$. A maximum 24-hour concentration of 0.18 $\mu g/m^3$ was reported in East St. Louis, Illinois.

During the summer and fall of 1969, the city of Helena was exposed to an average 24-hour concentration of 0.03 and a maximum 24-hour concentration of 0.11 $\mu g/m^3$. The residents of East Helena, depending upon their location within the city, were exposed to an average 24-hour concentration between 0.06 and 0.29 $\mu g/m^3$ and to a maximum 24-hour concentration of 0.7 $\mu g/m^3$.

The concentration of cadmium in the particulate matter that settles in the vicinity of the East Helena smelter is 200 to 1000 ppm. Each month, 1 to 4 mg of cadmium settles on each square meter of surface area within a 1-mile radius of the smelter.

Contamination of Water

Recognition of the toxic potential of cadmium when it is taken by mouth is based on the occurrence of poisoning from cadmium-contaminated food and beverages, epidemiologic evidence that cadmium may be associated with renal arterial hypertension, and long-term oral toxicity studies in animals.

According to the Public Health Service Drinking Water Standards, a drinking water supply containing in excess of 0.01 mg cadmium per liter should be rejected.

Water was sampled from Prickly Pear Creek (downstream of the smelting complex) on July 1, 1969; October 25, 1969; and April 4, 1970. The cadmium content was 0.006, 0.001, and 0.007 mg per liter, respectively. Limited sampling of other Helena Valley waters suggests that the concentration of cadmium generally is less than 0.001 mg per liter.

Contamination of Soil

The expected cadmium content of soils is 0.5 ppm. The concentration in the soil outside, but adjacent to, the Helena Valley ranged from less than 0.5 to 2 ppm.

The concentration of cadmium in the soil of the Helena Valley decreases with distance from the smelter. At a distance of 1, 2, and 4 miles, respectively, the upper inch of uncultivated soil contains 68, 17, and 4 ppm, and the upper 4-inch layer of cultivated soil contains 21, 9, and 3 ppm.

Lead

Lead can be seriously injurious to health as a result of accumulations in the body. Long-term daily intake of less than 0.6 mg by healthy adults may cause small increases in body burden, but no clinical disease. An intake in excess of 0.6 mg per day may result in the accumulation during a lifetime of a dangerous quantity of lead in the body.

Contamination of Air

Because maximum permissible atmospheric concentrations have not been established in the United States, judgment regarding the significance of lead contamination must be related to permissible body burden. Intake from the air can be approximated by assuming 20 percent retention of a daily intake of 20 cubic meters of air.

During the summer and fall of 1969, the city of Helena was exposed to an average daily concentration of 0.1 $\mu g/m^3$, with maximum daily concentrations up to 0.7 μg/m^3. The residents of East Helena, depending upon location within the city, were exposed to an average daily concentration of 0.4 to 4 μg/m^3, with maximum daily exposures up to 15 μg/m^3.

Daily respiratory intake in Helena is calculated to be 0.5 μg. In East Helena, the daily respiratory intake varies from 2 to 20 μg, depending upon location within the city.

Particles that settle from the air in the vicinity of the smelter contain 6,000 to 28,000 ppm. Ingestion of 0.007 to 0.04 ounce of these particulates may exceed the daily body-burden limit.

Within a 1-mile radius of the East Helena smelter, 30 to 140 mg of lead settles in particulate form each month on each square meter of surface area. Accordingly, each 0.5 to 2 square feet of surface area is contaminated each month by an amount equivalent to the daily body-burden limit for lead.

Contamination of Water

The lead concentration in drinking water supplies ranges from traces to 0.04 mg per liter, averaging 0.01 mg per liter. At concentrations of 0.1 mg per liter, bacterial decomposition of organic matter is inhibited and some fish are susceptible to lead poisoning. Adults consume 1 to 3 liters of drinking water per day.

The Public Health Service Drinking Water Standards state that 0.05 mg of lead per liter constitutes grounds for rejection of the water supply.

Helena Valley waters contain less than 0.001 to 0.04 mg per liter. The water in Prickly Pear Creek contained 0.044, 0.000, and 0.042 mg per liter on July 1, 1969, October 25, 1969, and April 4, 1970, respectively. Missouri River water at the Helena City Water Plant intake contained 0.033, 0.000, and 0.019 mg per liter on those respective dates.

Contamination of Soil

The expected lead content of soil is 16 ppm. The concentration in soil outside, but adjacent to, the Helena Valley is 15 ppm. The concentration in the soil of the Helena Valley decreases with distance from the smelting complex. At distances of 1, 2, and 4 miles, respectively, the upper inch of uncultivated soil contains 4,000, 600, and 100 ppm, and the upper 4-inch layer of cultivated soil contains 700, 250, and 90 ppm.

Zinc

Zinc is a normal constituent of the human body. It is taken into the body in the diet or by inhalation, and is eliminated by processes of excretion and perspiration. Excessive body intake, however, can result in zinc poisoning.

of cadmium settles on each square meter of surface area within a 1-mile radius of the smelter.

Contamination of Water

Recognition of the toxic potential of cadmium when it is taken by mouth is based on the occurrence of poisoning from cadmium-contaminated food and beverages, epidemiologic evidence that cadmium may be associated with renal arterial hypertension, and long-term oral toxicity studies in animals.

According to the Public Health Service Drinking Water Standards, a drinking water supply containing in excess of 0.01 mg cadmium per liter should be rejected.

Water was sampled from Prickly Pear Creek (downstream of the smelting complex) on July 1, 1969; October 25, 1969; and April 4, 1970. The cadmium content was 0.006, 0.001, and 0.007 mg per liter, respectively. Limited sampling of other Helena Valley waters suggests that the concentration of cadmium generally is less than 0.001 mg per liter.

Contamination of Soil

The expected cadmium content of soils is 0.5 ppm. The concentration in the soil outside, but adjacent to, the Helena Valley ranged from less than 0.5 to 2 ppm.

The concentration of cadmium in the soil of the Helena Valley decreases with distance from the smelter. At a distance of 1, 2, and 4 miles, respectively, the upper inch of uncultivated soil contains 68, 17, and 4 ppm, and the upper 4-inch layer of cultivated soil contains 21, 9, and 3 ppm.

Lead

Lead can be seriously injurious to health as a result of accumulations in the body. Long-term daily intake of less than 0.6 mg by healthy adults may cause small increases in body burden, but no clinical disease. An intake in excess of 0.6 mg per day may result in the accumulation during a lifetime of a dangerous quantity of lead in the body.

Contamination of Air

Because maximum permissible atmospheric concentrations have not been established in the United States, judgment regarding the significance of lead contamination must be related to permissible body burden. Intake from the air can be approximated by assuming 20 percent retention of a daily intake of 20 cubic meters of air.

During the summer and fall of 1969, the city of Helena was exposed to an average daily concentration of 0.1 $\mu g/m^3$, with maximum daily concentrations

Contamination of Air

Inhalation of zinc does not represent a significant health risk to the general population, but it is of concern in the field of occupational health. Exposure to air containing milligram quantities per cubic meter has resulted in metal-fume fever, a malaria-like illness that lasts about 24 hours and has never been known to be fatal.

Maximum permissible atmospheric concentrations for zinc have not been established. The 1967 American Conference of Governmental Industrial Hygienists adopted the value of 5 milligrams per cubic meter (mg/m^3) for zinc oxide fumes in occupational exposures.

During the summer and fall of 1969, airborne zinc in the Helena Valley, depending upon location, averaged less than 0.1 to 3 $\mu g/m^3$, with maximum 24-hour values up to 8 $\mu g/m^3$.

Contamination of Water

Zinc salts act as gastrointestinal irritants. Although the illness may be acute, it is transitory. The emetic concentration in water is 1 gram per liter. Communities have used waters containing up to 27 mg per liter without harmful effects.

Concentrations of about 30 mg per liter impart a milky appearance and a metallic taste. Concentrations below 4 mg per liter generally are not detectable by the human sense of taste.

Inasmuch as zinc in water does not cause serious effects on health but produces undesirable esthetic effects, it is recommended that concentrations of zinc be kept below 5 mg per liter.

Water supplies within the Helena Valley were found to contain 0.003 to 0.2 mg per liter.

Contamination of Soil

The expected zinc content of the soil is 44 ppm. The concentration in soil outside, but adjacent to, the Helena Valley is 58 ppm. The concentration of zinc in the soil of the Helena Valley decreases with distance from the smelting complex. At a distance of 1 mile, the upper inch of uncultivated soil and the upper 4-inch layer of cultivated soil contain 1,100 and 300 ppm. respectively, whereas at a distance of 2 miles from the complex both soils contain 200 ppm.

EVALUATION OF POLLUTANT EFFECTS

Vegetation

Leaf damage and contamination can be attributed to specific pollutants. Suppression of growth rate may occur as a result of pollution. From studies conducted during the summer of 1969, it was concluded that the vegetation growth rate was suppressed 15 percent in the vicinity of the city of East Helena.

Damage from Sulfur Dioxide

Within 1 mile of the smelter complex, sulfur dioxide leaf damage to indigenous alfalfa, corn, sweet potato, lettuce, tomato, grape, apple, and plum occurred during the summer of 1969.

Sulfur dioxide damage was identified histologically on pine trees growing within 0.5 mile of the smelter complex during 1969. In 1968, this type of damage was found at distances up to 4 miles from the smelter complex.

Arsenic Contamination

The tolerance for arsenic on sprayed fruits and vegetables set by the Food and Drug Administration is 3.5 ppm. Lettuce, carrot, beet, pinto bean, and alfalfa grown in the city of Helena in 1969 had an average arsenic content of 0.4 ppm.

Concentrations in edible portions of unwashed vegetables and crops grown in 1969 within a 4-mile radius of East Helena varied from 0.05 to 14 ppm on a wet basis. Pasture grass, barley straw, and alfalfa contained 0.4 to 14 ppm. Barley, wheat, and oat kernels contained 0.05 to 0.9 ppm. Onion, lettuce, carrot, and cabbage had maximum concentrations of 0.9 to 3 ppm. Apple, beet, kohlrabi, potato, radish, rutabaga, string bean, and garden peas had maximum concentrations of 0.05 to 0.5 ppm.

Cadmium Contamination

Lettuce, carrot, beet, bean, and alfalfa grown in the city of Helena during 1969 had an average cadmium content of 0.7 ppm.

The concentration in edible portions of unwashed vegetables and crops grown in 1969 within a 4-mile radius of East Helena varied from 0.05 to 10 ppm. Pasture grass, alfalfa, and barley straw contained 0.1 to 10 ppm. Barley, wheat, and oat kernels contained 0.1 to 1.5 ppm. Lettuce and beet maximum concentrations were 3.4 and 2.5 ppm, respectively.

Lead Contamination

Lettuce, carrot, beet, bean, and alfalfa grown in the city of Helena during 1969 had an average lead content of 1 ppm.

Concentrations in edible portions of unwashed vegetables and crops grown in 1969 within a 4-mile radius of East Helena varied from 0.1 to 100 ppm. Pasture grass, barley straw, and alfalfa contained 1.4 to 100 ppm. Barley, wheat, and oat kernels contained 0.1 to 10 ppm. Lettuce, beets, and cabbage had maximum concentrations of 17, 15, and 9 ppm, respectively.

Zinc Contamination

Lettuce, carrot, beet, bean, and alfalfa grown in the city of Helena in 1969 had an average zinc content of 12 ppm.

Concentrations in edible portions of unwashed vegetables and crops grown in 1969 within a 4-mile radius of East Helena varied from 0.5 to 230 ppm. Pasture grass, barley straw, and alfalfa contained 23 to 124 ppm. Barley, wheat, and oat kernels contained 23 to 86 ppm. Beet, lettuce, carrot, and garden peas had maximum concentrations of 68, 36, 36, and 22 ppm, respectively.

Animals

Systematic investigation of health abnormalities caused by air pollutants was not feasible during this study. Accumulation of heavy metals in hair, in organs, and in edible animal tissue was investigated.

Acute Effects on Health

Horses are more susceptible than other species of farm animals to the environmental toxicants that occur within the Helena Valley. The 1969 post-mortem report on a 3-year-old bay mare reads:

> 10/12 - about 4 pm on horse reported to have clinical signs of "smoked" horse syndrome. Frothy nasal exudata, congestion and consolidation in lungs with varying degrees of hepatization, grossly; not the severity of lung damage as seen in some previous cases on ranch. All other systems (no nervous exam) appeared grossly normal.

This report is consistent with chronic lead and/or cadmium exposure, pneumonia primary or secondary to heavy-metal exposure, and/or heart disease primary or secondary to heavy-metal exposure. The presence of toxic levels in the kidney (300 ppm cadmium and 3 ppm lead) and in the liver (80 ppm cadmium and 4 ppm lead) but not in the mane, indicates an acute rather than a long-term or chronic exposure.

Heavy-Metal Accumulation in Hair

Hair is a depot for arsenic, cadmium, and lead during long-term exposure to these metallic toxicants. Increasing levels of arsenic, cadmium, and lead in the manes of horses of the Helena Valley correlate with proximity to the smelter complex. Older horses, horses residing in the Valley for the longest duration, and chronically impaired horses have the highest concentrations of lead and cadmium. A significant percentage of the horses exhibit lead and cadmium levels that are two to five times the usual concentrations of cadmium and lead in horse mane hair.

Heavy-Metal Accumulation in Organs

Livers and kidneys of uncaged domestic rabbits living within 0.5 mile of the smelter complex contained elevated levels of cadmium and lead. Cadmium content of the livers from different rabbits varied from 4 to 9 ppm, and content of the kidneys varied from 20 to 60 ppm; the usual cadmium content is approximately 0.1 ppm for liver and 0.3 ppm for kidney. Lead content of the livers varied from 3 to 8 ppm, and content of the kidneys varied from 2 to 19 ppm; the usual lead content is less than 0.1 ppm.

Liver and kidney tissues of mice living in the Helena Valley also contained increased levels of cadmium and lead. The average cadmium content of liver tissue varied from 0.4 to 5 ppm, and the content of kidney tissue ranged from 1.5 to 14 ppm. Liver and kidney tissue of similar animals caught outside, but adjacent to, the Valley averaged 0.2 and 2 ppm cadmium, respectively. In liver tissue, the average lead content varied from 2 to 15 ppm and in kidney tissue, from 2 to 110 ppm. Liver and kidney tissue of similar animals caught outside, but adjacent to, the Valley both averaged 0.5 ppm lead.

Heavy-Metal Accumulation in Animal Foodstuffs

Delayed opening of a local slaughterhouse limited the evaluation of the hazard of foodstuffs derived from the animal population to samples that could be collected from local farms. Beef, swine, chicken, and rabbit muscle within 2 miles of the smelting complex contained maximum concentrations of 0.6 ppm arsenic, 0.4 ppm cadmium, 0.5 ppm lead, and 70 ppm zinc. Whole milk was found to contain a trace quantity of arsenic, 0.02 ppm of cadmium, 0.06 ppm of lead, and 5 ppm of zinc.

Humans

Investigation of air-pollution-related health impairment in the residents of the Helena Valley was not within the scope of this study. Investigations were made, however, of heavy-metal accumulation in human hair and body burdens of heavy metals.

Heavy-Metal Accumulation in Hair

The exposure of the residents of the Helena Valley to heavy metals was reflected by elevated concentrations of arsenic, cadmium, and lead in the hair of fourth-grade school boys. Elevated levels of these metals in hair have not been associated with any clinical illness in these children.

Average and maximum heavy-metal levels in hair are listed by city in Table 1-3.

Body Burden

Acceptable daily intake of trace metals is based upon analysis of common foodstuffs, air, and water and upon excretions. Estimated maximum daily intake levels for arsenic, cadmium, lead, and zinc are 0.9, 0.2, 0.4, and 13.0 milligrams, respectively.

The diet represents the major source of body intake of these heavy metals;

Table 1-3. HEAVY-METAL LEVELS IN HAIR FOR THREE CITIES
(ppm)

	Arsenic		Cadmium		Lead	
	Average	Maximum	Average	Maximum	Average	Maximum
East Helena	5.2	30	2.0	6	43	175
Helena	0.8	1	1.3	6	12	75
Bozeman[a]	0.4	1	0.9	3	8	22

[a] Bozeman, a neighboring city not believed to be influenced by contamination, is listed for the sake of comparison.

however, in areas of high contamination, ingestion of soil or dirt also may be a consideration. In East Helena, ingestion of 10 milligrams (0.0004 ounce) of the airborne settleable particulates will double the acceptable daily intake of lead. The ingestion of 200 milligrams of such particulate matter will result in an intake of cadmium that is double the acceptable level.

Assuming that garden vegetables contain heavy-metal contaminants equivalent to the maximum measured, and that garden vegetables provide the entire dietary souce of vegetables on a continuing basis, calculations indicate that the body burden will be exceeded for cadmium and lead. Tissue accumulation is to be expected. Although no acute health hazard is indicated, concern must be given to the effects that might occur following continuous exposure to these levels of cadmium and lead.

POLLUTANT SOURCES

Annually, industrial processes in the Helena Valley are the source of approximately 80,000 tons of sulfur dioxide and 6,000 tons of particulate matter. Additional particulates are also emitted from unpaved roads.

Industries of the East Helena smelting complex contribute the bulk of air pollution found in the Helena Valley. This complex consists of the lead smelter of the American Smelting and Refining Company, the zinc oxide plant of the Anaconda Company, and the paint pigment of the American Chemet Corporation.

The East Helena smelter of the American Smelting and Refining Company converts mineral ore to usable metal. Lead concentrates and crude ore are brought to the plant by rail. Ore concentrates contain 50 to 70 percent lead and 10 to 30 percent sulfur. Gondola cars (about 8 per day) are unloaded with a backhoe onto moving belts that carry the material up to receiving bins. Crude ore is put through a crusher before being put into a bin. Concentrates are mixed with zinc residues, limestone, and siliceous ore; the material is pelletized and then delivered by belt conveyor to the sintering plant, where the mixture is fused by burning off the sulfur. The resulting sintered ore concentrate is mixed with coke and charged into the top of a blast furnace. The charge, about 1,000 tons of material per day, is ignited, melted, and reacted to form lead bullion and slag. Lead and slag flow from the furnace continuously into a brick-lined settler. Slag overflows the settler into slag pots and is transferred by rail either to the Anaconda zinc oxide plant or to the slag pile. Lead bullion is tapped into pots and transferred by rail to the drossing plant. In the drossing plant, the lead is poured into one of several large (90-ton) kettles and allowed to cool. Copper, having a higher melting temperature, crusts or drosses. The dross floats on top and is skimmed off; after being mixed with soda ash and coke breeze, the dross is transferred to a reverberatory furnace where it is smelted for further separation of zinc and lead according to density. Molten lead flows to the bottom and a layer of slag floats to the top. Just under the slag, copper matte (metal sulfides) forms, and copper speiss (metal arsenides and antimonides) settles just over the molten lead. The matte and speiss are cooled and shipped out of the area to a copper recovery plant. Molten lead is recycled to the drossing kettles. Lead in the drossing kettle is further purified by the addition of sulfur and by cooling, which results in further removal of copper as matte. The lead is then cast into 10-ton ingots and shipped out of the area to a lead refinery.

The zinc oxide plant of the Anaconda Company recovers zinc from the lead smelter slag. Daily, 100 tons of zinc oxide is recovered from approximately 500 tons of smelter slag. Molten slag received directly from the lead smelter or from cold storage is transported by rail in large pots and dumped into the top of a furnace. Pulverized coal and air forced into the bottom of the slag bath heat the mixture to 2,200° F. Zinc is vaporized, oxidized, and drawn from the furnace through a flue-and-cooling system, where the oxides solidify. The air stream bearing the solid oxides is forced through a baghouse that collects the zinc oxide. Molten slag, drawn from the bottom of the furnace into pots, is taken by rail and dumped on the waste slag pile.

The paint pigment plant of the American Chemet Company modifies zinc and copper oxides. Daily, 15 tons of zinc oxide from the zinc fuming plant is heated with natural gas in rotary kilns to improve the whiteness quality by removing traces of coal and by reacting any remaining sulfur. This product is then pulverized and packed in bags for outside distribution. Additionally, up to 100 tons per day of zinc oxide from a different source can be pulverized. This plant also has the capacity to produce 150 tons per day of cupric oxide pigments. Crude cupric oxide is reduced in a closed retort, milled, and packaged for distribution.

Sulfur Dioxide Emissions

The East Helena lead smelter and zinc recovery plants collectively account for 99 percent of the Helena Valley sulfur dioxide emissions.

Lead Smelter

During the normal production rate of 1,200 tons of feed per day, the smelter emits 330 tons of sulfur dioxide. The charge stock contains up to 30 percent sulfur, of which 89 percent is released during the sintering operation, 4 percent is released from the blast furnace, and 7 percent remains with the slag. Small amounts are released from the slag dump, the drossing plant, and the reverberatory furnace. Off-gases from the sintering operation pass through an electrostatic precipitator for dust removal and are discharged to the atmosphere from a 400-foot stack. Off-gases from the blast and reverberatory furnaces are combined, pass through a baghouse, and are discharged into the atmosphere at an elevation of 117 feet.

No attempt is made to curtail emissions by either recovery or removal of sulfur from the gaseous emissions. In July 1970, the Montana State Board of Health adopted an emission standard stating that within 3 years the amount of sulfur that may be released into the atmosphere in gaseous form must be less than 10 percent of the amount contained in the process raw material.

The 400-foot stack is used to reduce the impact of emissions from the sintering operation at ground level near the smelter. In the spring of 1970, an induced draft fan and stack heater were added to reduce such impact further. Three ground-level sulfur dioxide monitoring stations are operated in the smelter area by the American Smelting and Refining Company. Reportedly, if a monitor detects a concentration of 0.7 ppm that persists for 15 minutes, the sintering plant is shut down and is not started up until the monitor indicates a concentration of less than 0.5 ppm for 15 minutes.

Sulfur dioxide emissions from the sintering operation can be reduced by conversion to and recovery as sulfuric acid, by conversion to and recovery as sulfur, or through removal by scrubbing. Sulfur dioxide emissions from the baghouse can be reduced by a limestone scrubber.

Zinc Recovery Plant

Operating at a production rate of 100 tons of product per day, the plant emits 13 tons of sulfur dioxide. The raw material is 2 percent sulfur, and the resulting waste slag is 1 percent sulfur. Sulfur dioxide is emitted from the charging of the furnace, from the baghouse, and from the slag pile.

Sulfur dioxide emitted from the baghouse and from furnace charging can be reduced by cleaning the effluent with a limestone-type scrubber. Emissions from the slag-dumping operation can be eliminated by the use of a granulating-type operation in which the molten residue slag is quenched by a stream of water, inside an enclosure, and the effluent gases are vented to a limestone scrubber.

Source-Receptor Relationships

Estimates of contributions from individual sources to the ambient pollutant concentrations were made using sulfur dioxide emission data and meteorological measurements of air movement. Sources considered were the zinc fuming plant baghouse, the smelter baghouse, and the 400-foot stack from the smelter.

Depending upon atmospheric stability, the point of maximum impact of the baghouses generally will occur at distances of 0.2 to 2 miles from the source. The maximum 1-hour sulfur dioxide concentrations expected are 0.6 to 0.9 ppm from the Anaconda baghouse and 1 to 3 ppm from the smelter baghouse. The maximum point of impact from the 400-foot stack can occur at distances of 0.4 to 31 miles, and respective 1-hour values of 5 and 0.2 ppm can be expected. The maximum point of impact from the 400-foot stack when heater and fan are operating will occur at distances of 0.5 to 43 miles, and concentrations of 2 and 0.1 ppm, respectively, can be expected.

Aerodynamic downwash of the baghouse emissions is expected to cause concentrations in excess of 8 ppm whithin the city of East Helena.

Diffusion calculations of annual mean concentrations, neglecting downwash phenomena, throughout the Helena Valley predict that: 75 percent of the atmospheric sulfur dioxide in Helena originates from the 400-foot stack (with fan and heater); 85 percent of the atmospheric sulfur dioxide in East Helena originates from the baghouses; and 50 percent of the atmospheric sulfur dioxide in the area southeast of the city of East Helena originates from the 400-foot stack.

Particulate Emissions

Industrial processes and fuel use account for 98 percent of the estimated particulate emissions. Unpaved streets in the area emit an unknown quantity of particulates; the seriousness of these emissions is compounded by the number of unpaved streets in use and by the cadmium and lead contamination of road dirt in East Helena.

Lead Smelter

When operating at a normal production rate of 1,200 tons of feed per day, the smelter is estimated to emit 1,000 pounds of particulate matter that contains substantial concentrations of arsenic, cadmium, lead, and zinc. Known points of emission include the material-receiving area during unloading of concentrates, the outside yard area used for storage of concentrates, and the baghouse through which off-gases from the sintering furnace pass to the atmosphere.

Only minimal efforts have been made by the company to control emissions from material handling. Particulates in the off-gases of the blast and reverberatory furnaces are estimated to be 99 percent controlled by the baghouse. Particulates in the off-gases of the sintering furnace are controlled by an electrostatic precipitator reported to be 97 percent efficient, but the reported efficiency is questionable because of the age of this precipitator.

Zinc Recovery Plant

Quantitative estimates of emissions are not available; but known points of emissions are the furnace, the baghouse, the slag dump, and the coal pulverizer. When slag is charged into the furnace, copious emissions of white fumes, believed to contain high concentrations of cadmium, lead, and zinc, are emitted at the charging door. The product, zinc oxide, is collected by a baghouse with a high collection efficiency. Disposal of slag is estimated to emit in excess of 1 ton per day of particulate matter, and coal crushing emits a sizable but undetermined quantity of coal dust.

The company has made no efforts to control particulate emissions from the charging of the furnace and from the dumping of slag. A baghouse has been installed to control emissions from the coal crusher.

Source-Receptor Relationships

Neither the amounts nor the physical and chemical properties – such as size, shape, density, and chemical content – of particles emitted by industrial sources in East Helena are known. Quantitative estimates cannot be made, therefore, of the distribution of particles and heavy metals at ground level. Unlike gases, particulates attain some downward settling velocity. Accordingly, maximum ground-level airborne particulate and heavy-metal concentrations occur closer to the sources than do the maximum concentrations predicted for sulfur dioxide.

Waste Water Emissions

Lead Smelter

Plant effluent, consisting of cooling water and process wash water, is discharged into holding ponds that connect with Prickly Pear Creek. Cooling water is cycled at a rate of 1,450 gallons per minute between the plant and the retention ponds. Water from the washing of speiss is discharged into the ponds for a period of 1 hour per day at a rate of 600 gallons per minute.

Speiss wash water is high in heavy-metal content. Analysis by the State of Montana of the pond discharge into the creek indicates the following metals and their concentrations in parts per million: arsenic, 0.8; copper, 1.1; lead, 0.6; and iron, 1.1.

Zinc Oxide Plant

Process and cooling water from this facility is held in ponds for recirculation, with no discharges being made into Prickly Pear Creek or any other portion of the Valley's drainage system.

Solid Waste Disposal

Lead Smelter

Process slag from past operations is stored on plant property near Prickly Pear Creek. Upon demand, this slag is taken to the zinc oxide plant for further processing.

Zinc Oxide Plant

The waste slag is taken in pots by rail and dumped on the large waste-slag pile located between the smelting complex and the city of East Helena.

2. SURVEY OF AIRBORNE POLLUTANTS

Norman A. Huey
ENVIRONMENTAL PROTECTION AGENCY
REGION VIII OFFICE

INTRODUCTION

The pollutants surveyed in the study area were sulfur dioxide, airborne particulates, arsenic, cadmium, lead, and zinc. All measurements were made between June and November 1969 except for sulfation measurements, which were continued until June 1970.

Sulfur dioxide was measured with continuous monitors at 5 locations and with sulfation plates[1] at approximately 200 locations. Measurements related to sulfur dioxide pollution, i.e., sulfate and total acidity, were also made on suspended particulates.

Total suspended and total settleable particulates (dustfall) were measured at 5 locations; windblown particulates and soiling index were measured at 40 and 4 locations, respectively.

Arsenic, cadmium, lead, and zinc contents were determined in suspended and settleable particulates.

Ozone and nitrogen oxides were measured by continuous monitors for brief periods of time at one or two locations in conjunction with the vegetation-effect investigations.

SULFUR DIOXIDE

Point Measurements of Sulfur Dioxide

From June to November 1969, continuous monitors (Beckman* 906 coulometric instruments) were operated at sampling stations 1, 2, 3, 4, and 5 shown in Figure 2-1.

The results from these instruments were reduced manually in the field by the operating personnel. The number of occurrences and the length of each occurrence that each instrument indicated was greater than preselected sulfur dioxide levels were recorded daily. This information is summarized for the entire sampling period in Table 2-1. These data are presented to show that infrequent, short-term, high levels of sulfur dioxide occur. Levels in excess of 2 parts per

---

*Mention of a specific company or product does not constitute endorsement by the Environmental Protection Agency.

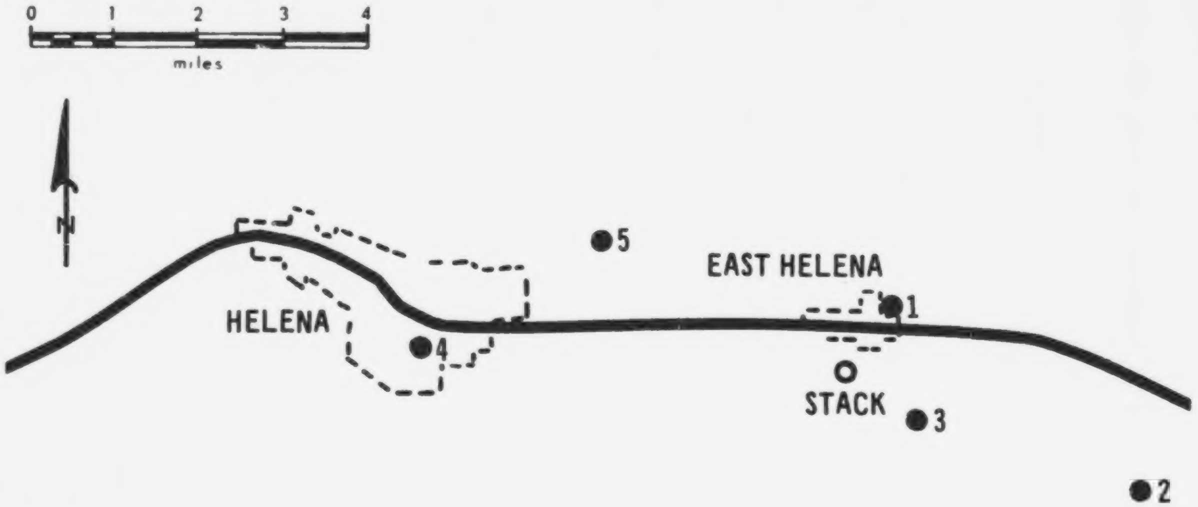

0
1
2
3
4
miles
N
HELENA
EAST HELENA
STACK
1
2
3
4
5

Figure 2-1. Sulfur dioxide monitoring locations.

Table 2-1. NUMBER OF OCCURRENCES AND LENGTH OF TIME SPECIFIC LEVELS EXCEEDED

Sampling station	Number of times and number of minutes specific levels exceeded													
	>4 ppm		>2 ppm		>1 ppm		>0.5 ppm		> 0.2 ppm		> 0.1 ppm		<0.1 ppm	
	times	minutes	times	minutes	times	minutes	times	minutes	times	minutes	times	minutes	times	minutes
1	0	0	11	41	32	186	52	579	109	1447	159	2867	–	117,063
2	0	0	8	33	31	175	101	723	264	2413	408	5195	–	161,225
3	1	2	66	388	148	1075	314	2563	533	6182	663	10,311	–	174,539
4	0	0	0	0	4	48	19	273	76	1358	155	4041	–	174,509
5	0	0	0	0	3	7	27	143	74	1036	112	2446	–	159,444

million (ppm) were measured at sampling sites 1, 2, and 3. At sampling site 3, 2 ppm SO_2 was exceeded on 66 occasions for a total time of 388 minutes, or for about 6 minutes per occurrence. Sampling sites 1 and 3 represent the range of pollution that might be expected in East Helena. Sampling site 4 is representative of Helena.

The recorder strip-charts from these same monitors were later further reduced to produce 10-minute average concentrations. Using these values as input, a computer produced the frequency distribution of daily, hourly, and 10-minute values for each sampling location (Figures 2-2 through 2-6).

Spatial Distribution of Sulfur Dioxide

To improve the estimates of sulfur dioxide pollution throughout the entire Valley, 200 sampling stations using sulfation plates[1] were established. Sulfation measurements were made monthly from June through November of 1969. Sulfation measurements after November were made on a 3-month basis until June 1, 1970 The sulfation results were used as input to an IBM 1130 scientific computer. The computer, utilizing an IBM contour-mapping software package and a CAL-COMP plotter, was instructed to draw maps showing the distribution of sulfur dioxide throughout the Valley. Figures 2-7 through 2-16 were made from these computed maps. Figure 2-7 is a map of the sulfur dioxide pollution from June 1969 through May 1970. The map indicates that a small area in the center of the city of East Helena was polluted to a level greater than 0.04 ppm sulfur dioxide annual average. A larger area (approximately 10 square miles) lying adjacent to and southeast of East Helena was polluted to a level greater than 0.02 ppm SO_2.

Figure 2-8 is a map of the spatial distribution of sulfur dioxide during the active study period. The period covered includes the months of July, August, September, and October 1969. June 1969 was not included since during that month the plants of the industrial complex were operating only 50 percent of the time.

Figures 2-9 through 2-14 present the spatial distribution by month from June to November 1969. Figure 2-9, representing June 1969, shows a great contrast in pollution when compared to other months. Figure 2-14 indicates that the sulfur dioxide pollution increased dramatically between October and November. Figure 2-15 represents the spatial distribution of sulfur dioxide pollution during the winter months of December 1969, January 1970, and February 1970, indicating that the ambient air quality remained equivalent to the November 1969 level. During the spring months (Figure 2-16), the air quality improved.

The sulfation values were converted to sulfur dioxide values by means of the relationship: 1 mg $SO_3/100\ cm^2$-day is equivalent to 0.035 ppm SO_2.[2,3] This empirical relationship was derived from numerous parallel sulfur dioxide and sulfation measurements made in other studies. The validity of this relationship is verified for the Helena Valley area by comparison of the sulfation measurements made in the vicinity of the continuous monitors.

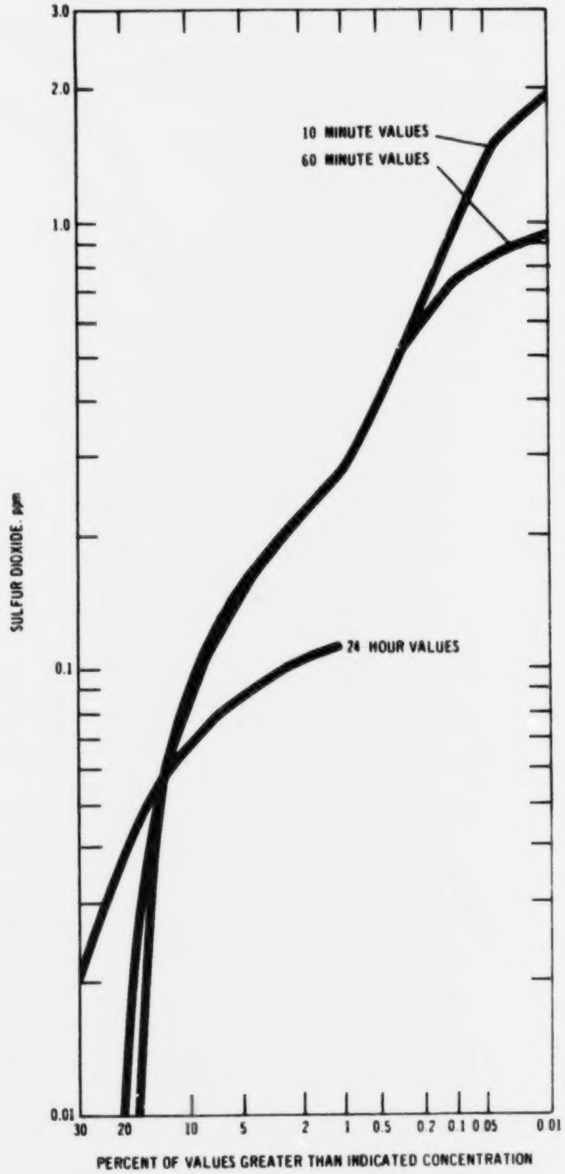


Figure 2-2. SO_2 frequency distribution at sampling location 1.

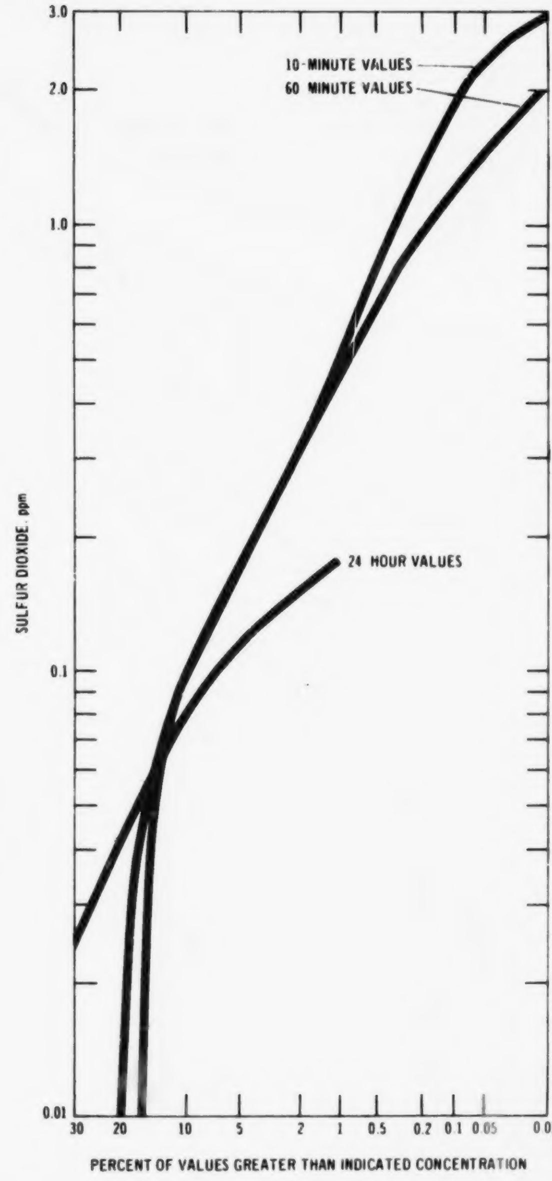


Figure 2-3. SO_2 frequency distribution at sampling location 2.

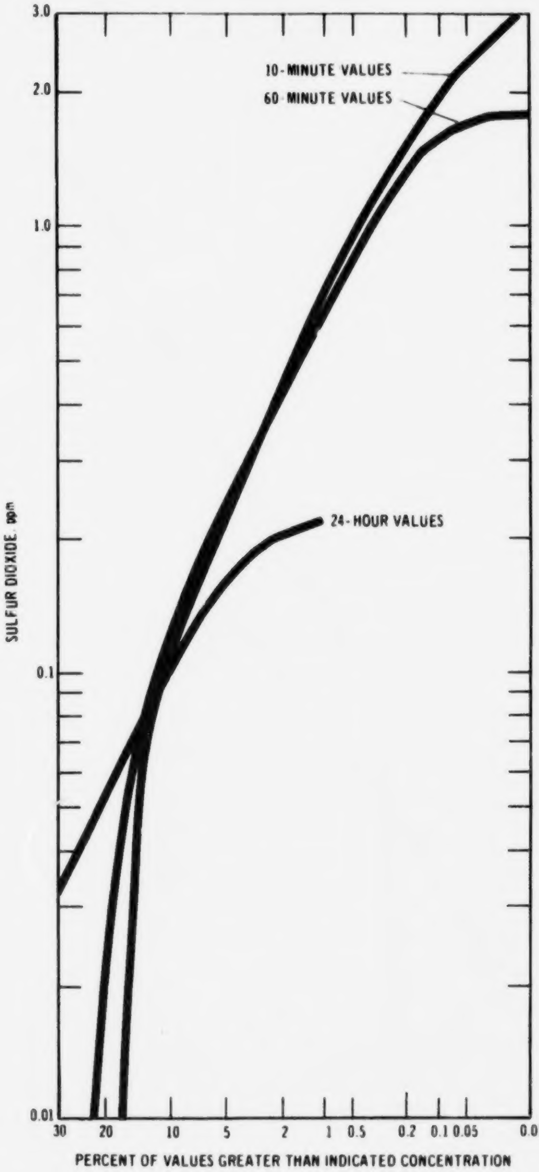


Figure 2-4. SO_2 frequency distribution at sampling location 3.

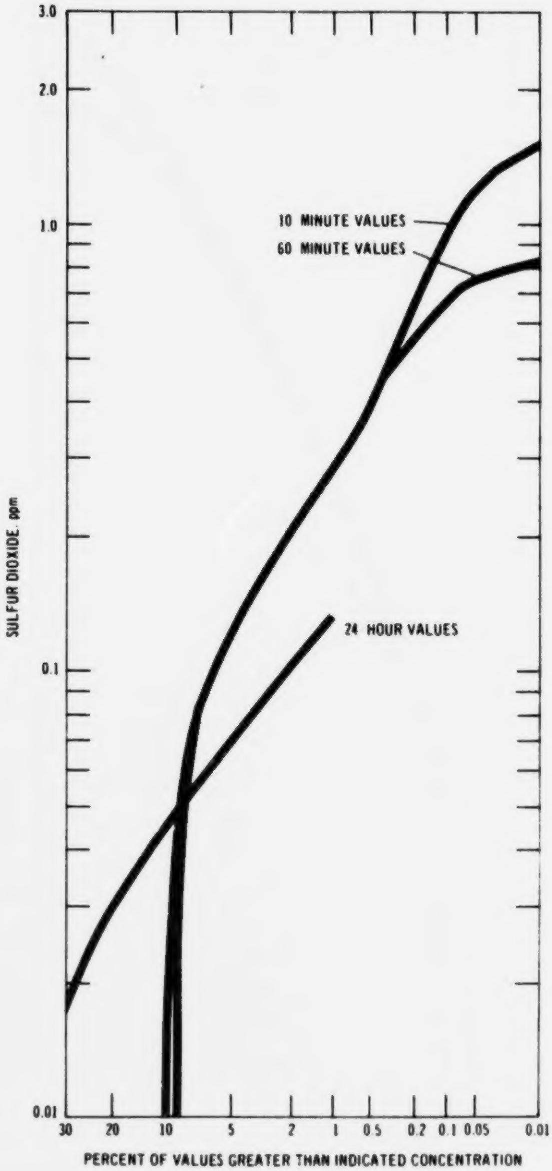


Figure 2-5. SO_2 frequency distribution at sampling location 4.

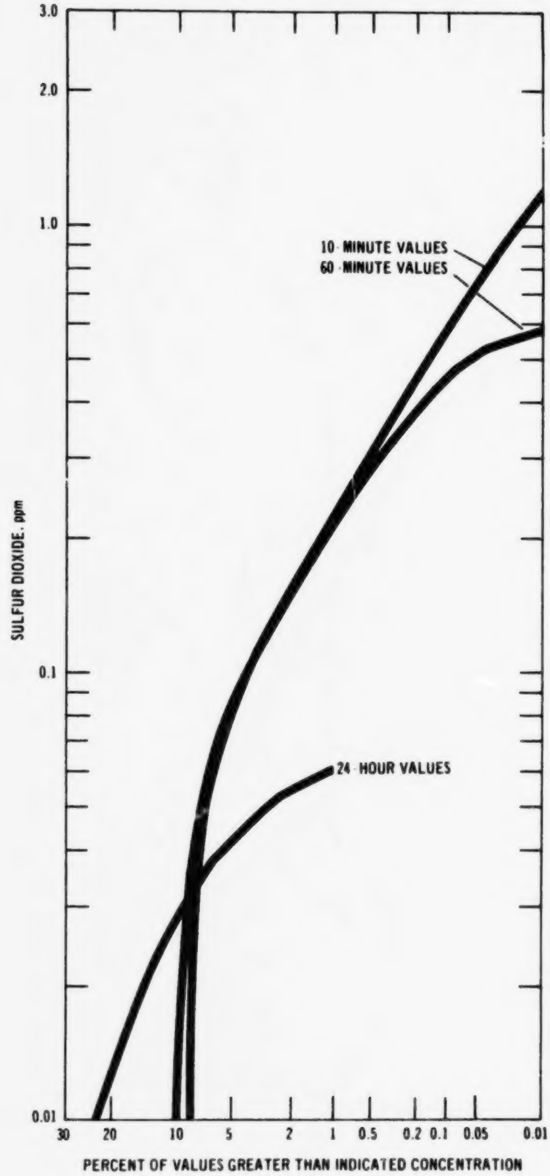


Figure 2-6. SO_2 frequency distribution at sampling location 5.

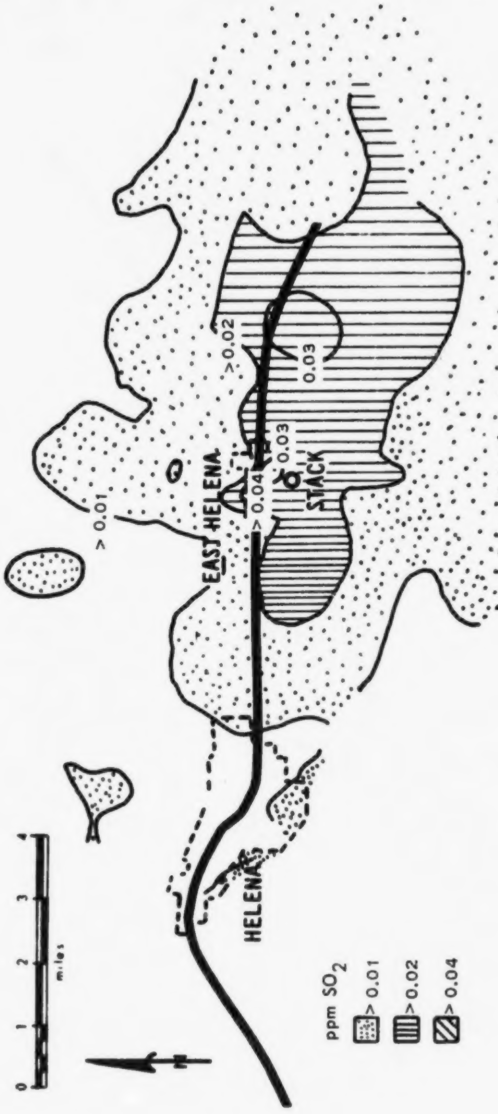

EAST HELENA
HELENA
STACK
> 0.01
>0.02
0.03
> 0.04
0.03
ppm SO_2
> 0.01
> 0.02
> 0.04
miles
0
1
2
3
4
N

Figure 2-7. Annual average spatial distribution of SO_2, June 1969 through May 1970.

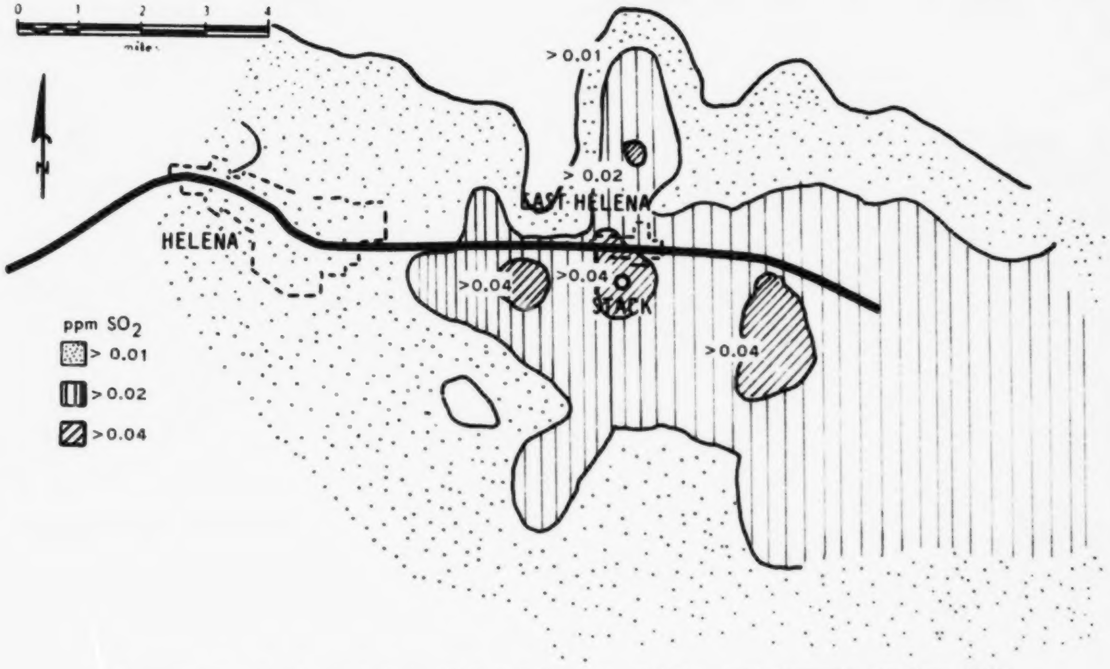

0
1
2
3
4
miles
N
HELENA
EAST HELENA
STACK
> 0.01
> 0.02
> 0.04
> 0.04
> 0.04
ppm SO_2
> 0.01
> 0.02
> 0.04

Figure 2-8. Study period spatial distribution of SO_2, July through October 1969.

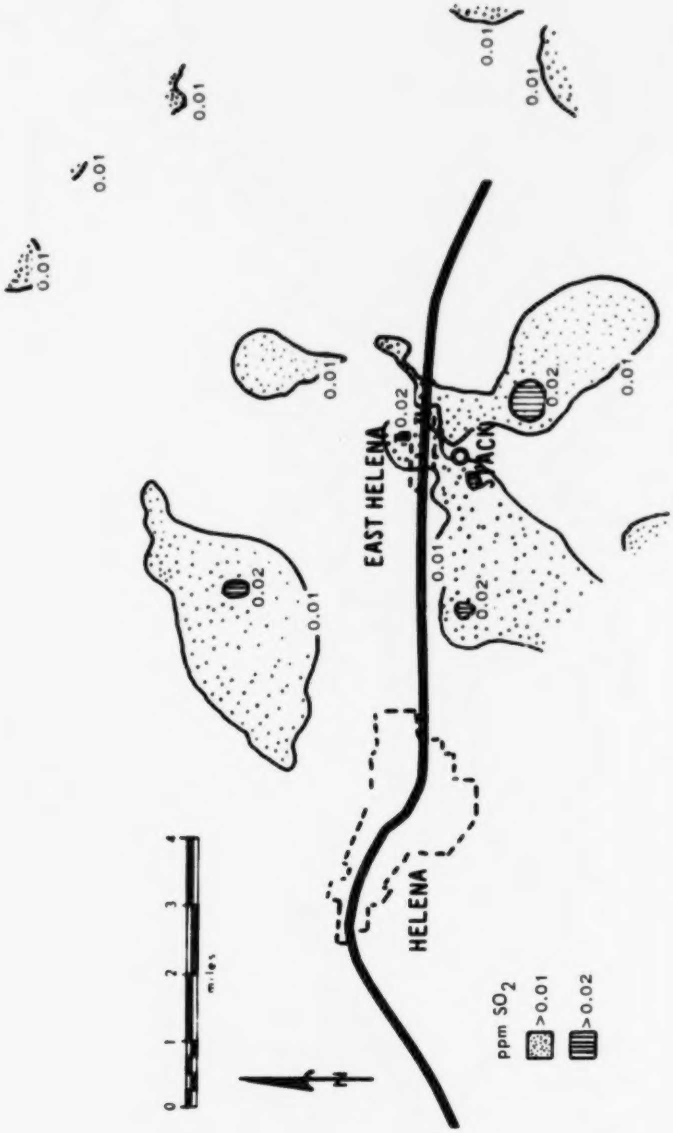

0.01
0.01
0.01
0.01
0.01
0.01
0.01
0.02
0.02
0.01
0.01
0.02
0.01
0.02
0.01
STACK
EAST HELENA
HELENA
0
1
2
3
4
miles
N
ppm SO_2
>0.01
>0.02

Figure 2-9. Spatial distribution of SO_2 during partial plant shutdown, June 1969.

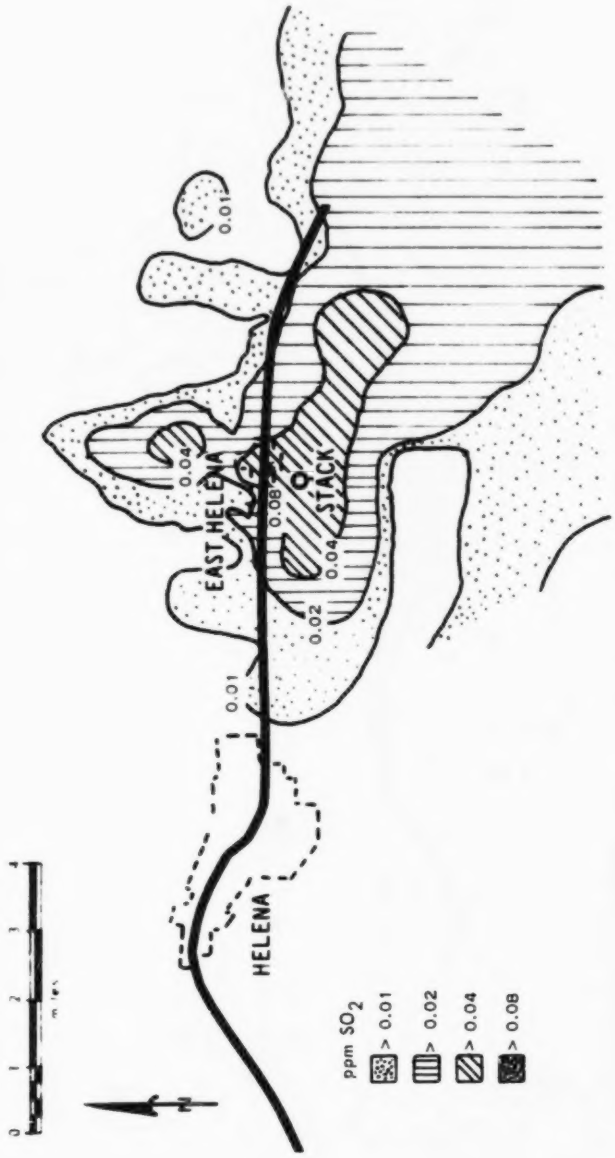

HELENA
EAST HELENA
STACK
0.01
0.01
0.02
0.04
0.04
0.08
ppm SO$_2$
> 0.01
> 0.02
> 0.04
> 0.08
miles
0
1
2
3
4
N

Figure 2-10. Spatial distribution of SO$_2$, July 1969.

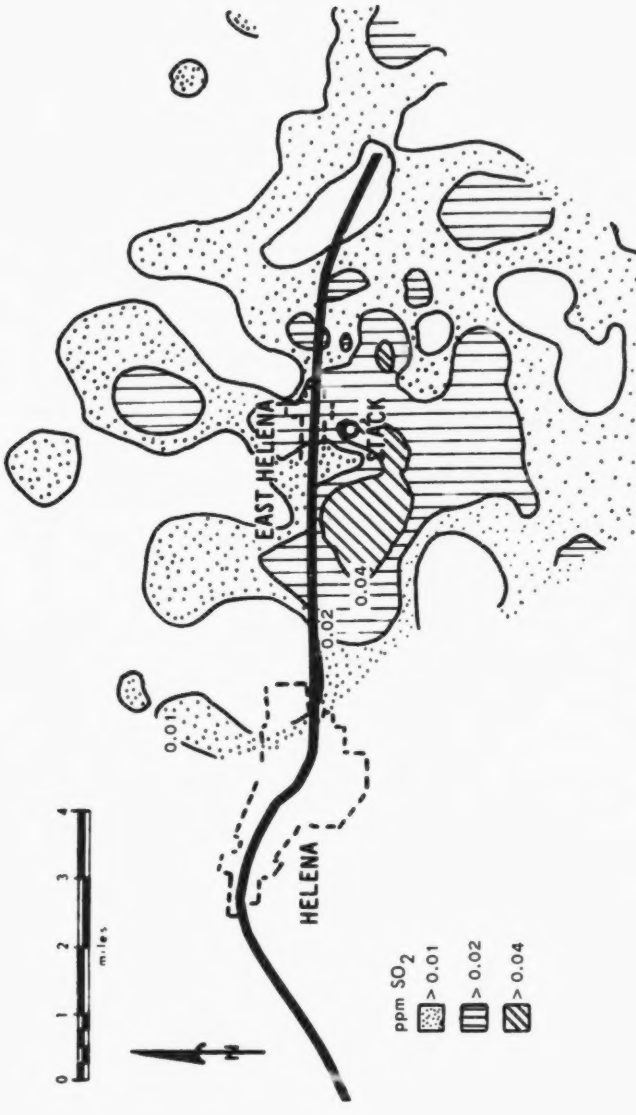

EAST HELENA
STACK
HELENA
0.01
0.02
0.04
0
1
2
3
4
miles
N
ppm SO_2
> 0.01
> 0.02
> 0.04

Figure 2-11. Spatial distribution of SO_2, August 1969.

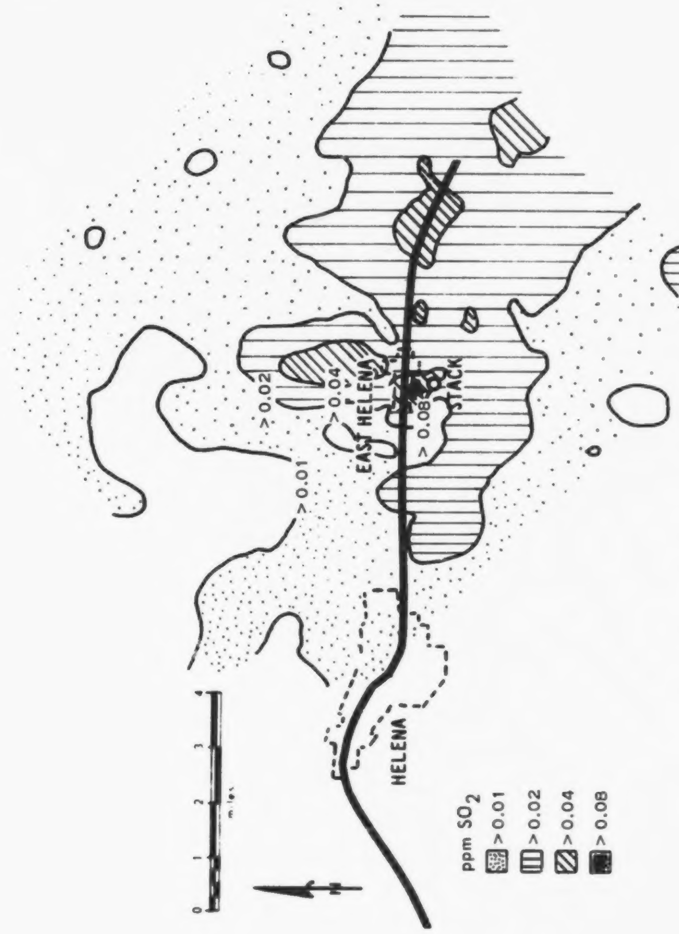

ppm SO_2
▦ > 0.01
▤ > 0.02
▨ > 0.04
■ > 0.08
HELENA
EAST HELENA
STACK
> 0.01
> 0.02
> 0.04
> 0.08
miles
0
1
2
3
4
N

Figure 2-12. Spatial distribution of SO_2, September 1969.

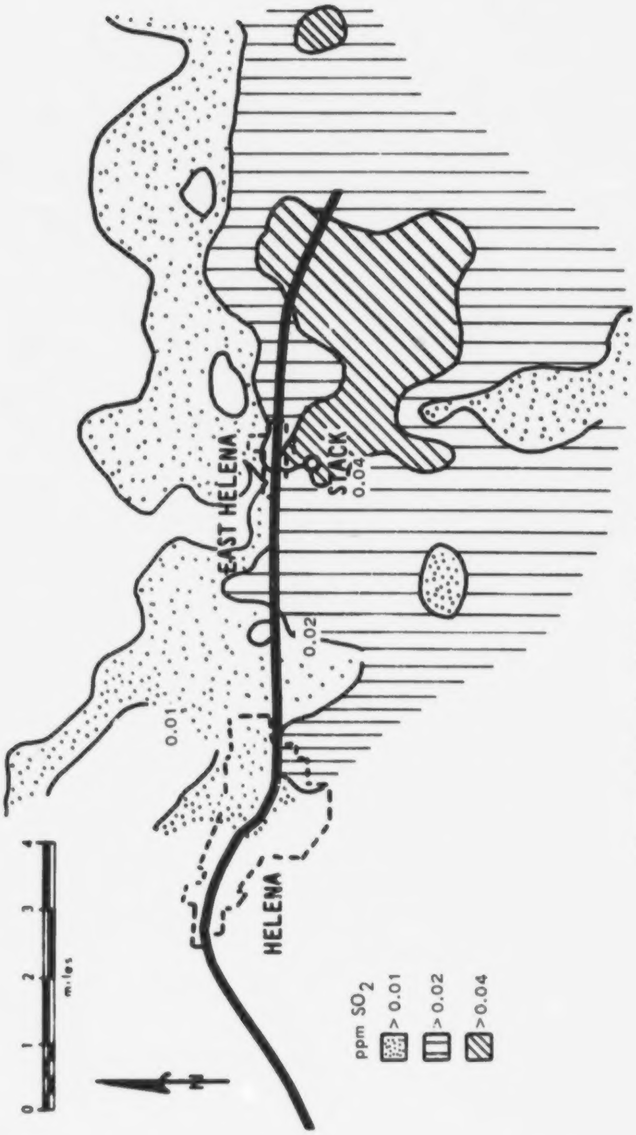

EAST HELENA
STACK
HELENA
0.01
0.02
0.04
0 1 2 3 4
miles
N
ppm SO_2
▨ > 0.01
▥ > 0.02
▧ >0.04

Figure 2-13. Spatial distribution of SO_2, October 1969.

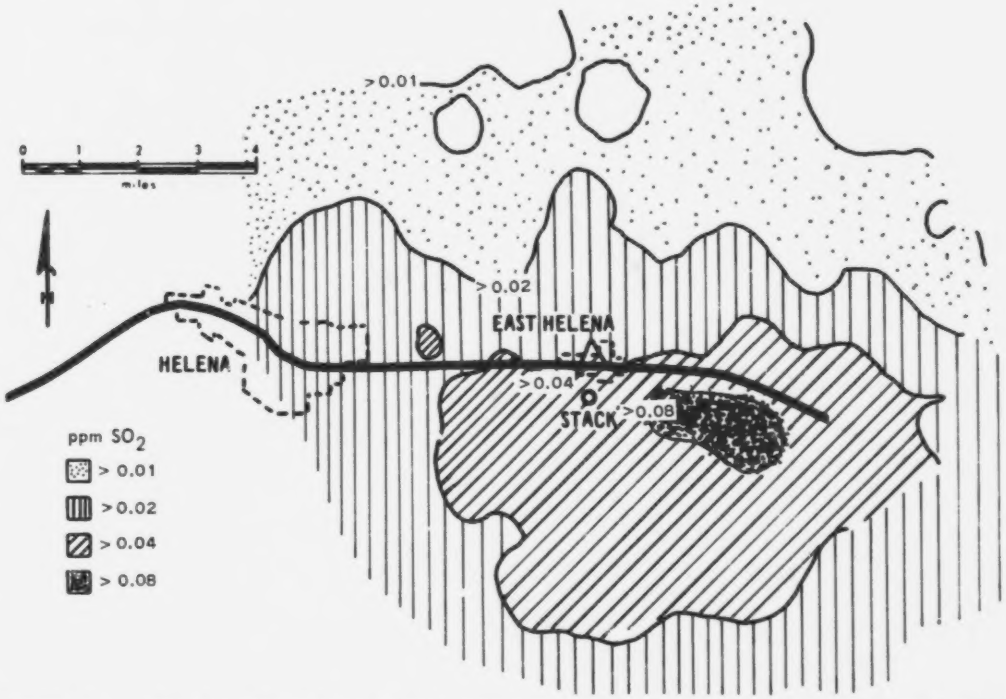

>0.01
>0.02
>0.04
>0.08
EAST HELENA
HELENA
STACK
0 1 2 3 4
miles
N
ppm SO_2
> 0.01
> 0.02
> 0.04
> 0.08

Figure 2-14. Spatial distribution of SO_2, November 1969 (1 month after end of study period).

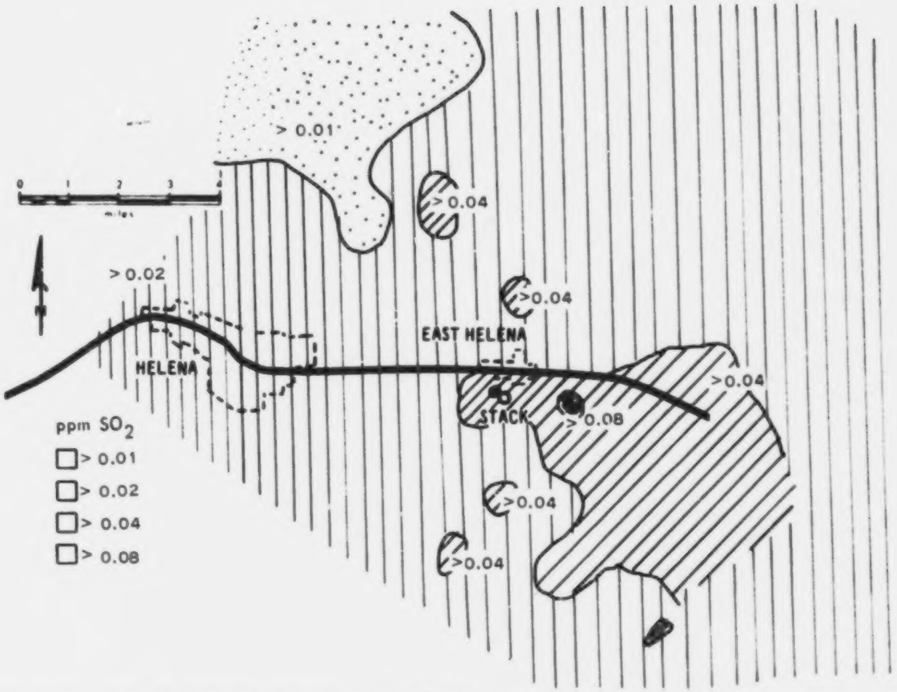

0
1
2
3
4
miles
> 0.01
> 0.02
> 0.04
>0.04
>0.04
>0.04
>0.04
> 0.08
HELENA
EAST HELENA
STACK
ppm SO_2
☐> 0.01
☐> 0.02
☐> 0.04
☐> 0.08

Figure 2-15. Winter spatial distribution of SO_2, December 1969 through February 1970.

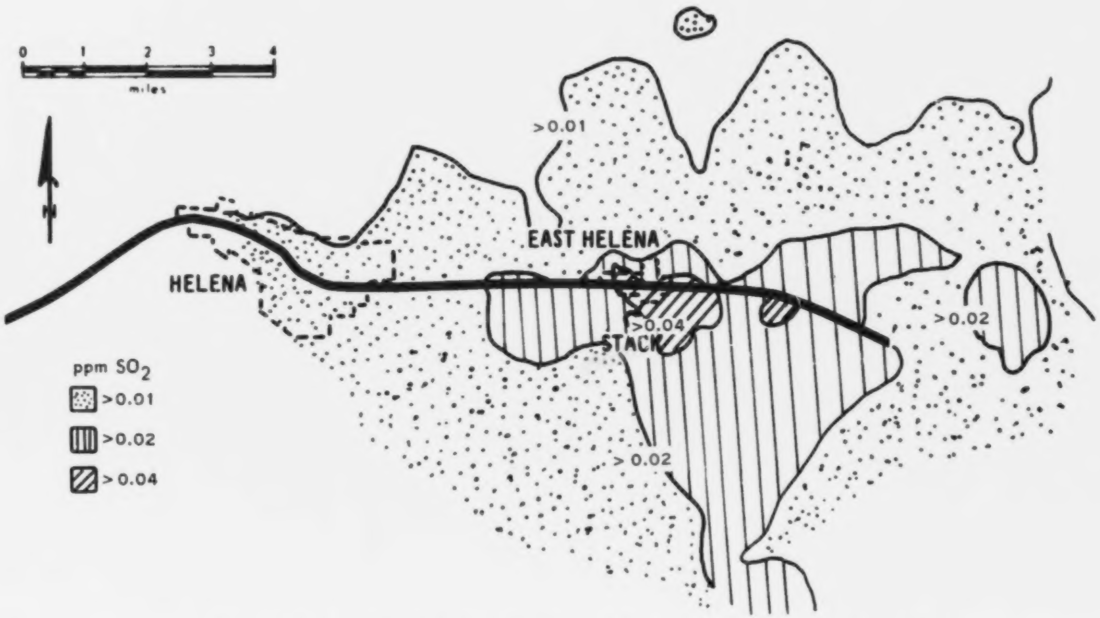

0
1
2
3
4
miles
N
HELENA
EAST HELENA
STACK
>0.01
>0.02
> 0.02
>0.04
ppm SO_2
>0.01
>0.02
> 0.04

Figure 2-16. Spatial distribution of SO_2, March through May 1970.

Table 2-2 contains the sulfation predictions along with the measured sulfur dioxide values. The predicted values are in agreement generally within 0.01 ppm of the measured values. The degree of validity of the measured values is not known precisely; however, it is unlikely that they would deviate from the true value by as much as 0.01 ppm. Accordingly, it should be concluded that any individual sulfation value in this area is capable of predicting the true average sulfur dioxide level within 0.01 ppm.

Table 2-2. COMPARISON OF SULFATION PREDICTIONS WITH MEASURED PPM VALUES

(ppm)

	Sampling station									
	1		2		3		4		5	
Month	x[a]	y[b]	x	y	x	y	x	y	x	y
June	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	–
July	0.04	–	0.03	0.05	0.06	0.07	0.01	0.01	0.02	–
August	0.04	0.03	0.03	0.03	0.04	0.02	0.02	0.01	0.01	–
September	0.03	0.04	0.05	0.06	0.04	0.05	0.02	0.02	0.01	0.01
October	0.01	0.02	0.04	0.05	0.05	0.06	0.02	0.03	0.01	0.02
Mean	0.02	0.03	0.03	0.04	0.04	0.04	0.01	0.01	0.01	0.01

[a] x = ppm value from monitor.

[b] y = ppm value predicted from sulfation.

Long-Term Trends

Figure 2-17 is a graphical representation of the monthly sulfur dioxide levels experienced at the East Helena City Hall from July 1968 through November 1969. These values were estimated from sulfation data.[3] Over the entire period of time, the sulfur dioxide averaged 0.10 ppm, with monthly fluctuations ranging from 0.04 to 0.18 ppm. This high variability is typical of areas with large point sources. Five of the six active sampling months (June through November 1969) are below the average for the entire period. It should be concluded that sulfur dioxide pollution in the 1969 summer period was lower than it had been in the previous year.

Sulfur Dioxide Related Measurements

Total acidity and sulfate content of suspended particulate matter are considered to be sulfur dioxide related. Particulate sulfate and total acidity measurements were made of the total suspended particulate samples that were collected on glass-fiber filters.

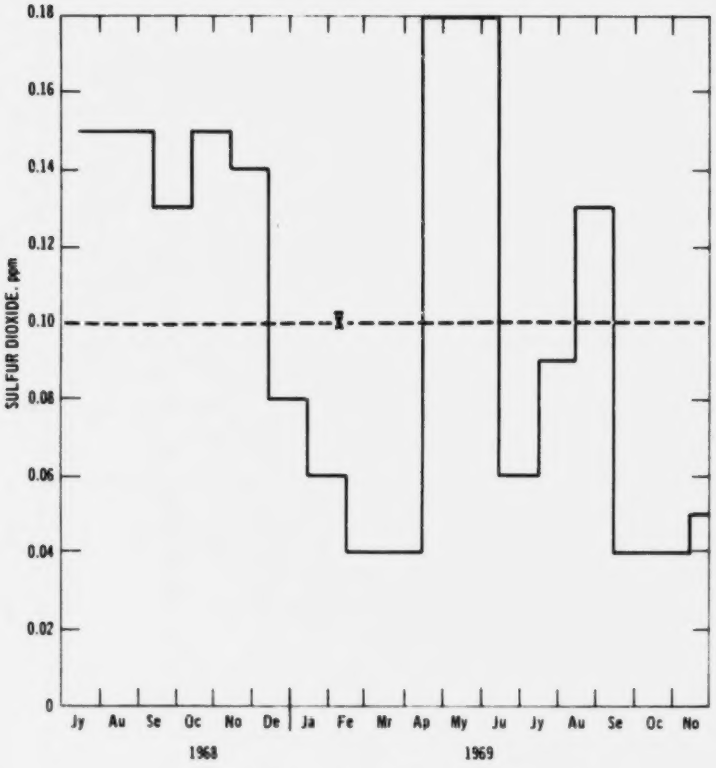


Figure 2-17. Sulfur dioxide trend from July 1968 to November 1969.

Table 2-3 contains summary statistics concerning the sulfate content of suspended particulate matter. These results are considerably below the national average and serve to point out that there is no problem from sulfates. It should also be noted that the sulfate content is evenly distributed among the five sampling stations, which indicates that there is no significant increase in concentration in the vicinity of the East Helena industry.

Table 2-4 contains summary statistics concerning the total acidity of the suspended particulates. Total acidity is a useful measurement in that it is capable of detecting occurrences of severe acid aerosol pollution. These results do not show a severe problem. The negative results are caused by the alkaline nature of the suspended particulates in this area.

Table 2-3. PARTICULATE SULFATE SUMMARY STATISTICS

Station	Location[a]		Sampling period	Statistics, $\mu g/m^3$											
	Degrees	Miles		N	$\overline{X}$	S	$\overline{X}_g$	S_g	Min	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	Max
1	34	0.8	June through October 1969	76	3.5	1.4	3.3	1.5	0.9	2.0	2.5	3.4	4.2	5.2	8.6
2	105	2.5	June through October 1969	88	3.7	1.5	3.4	1.5	0.9	2.0	2.6	3.5	4.3	5.7	9.8
3	112	0.4	June through October 1969	87	4.1	1.8	3.7	1.7	0.3	2.1	3.1	3.9	4.9	6.6	9.6
4	274	4.5	June through October 1969	84	2.9	1.6	2.5	1.8	0.3	1.1	1.7	2.5	3.9	5.2	7.0
6	2	0.5	September through October 1969	34	4.5	1.8	4.0	1.7	1.1	–	–	–	–	–	7.7

[a] Degrees are computed from north side of ASARCO stack in clockwise direction.

Table 2-4. PARTICULATE ACIDITY SUMMARY STATISTICS

Station	Location[a]		Sampling period	Statistics, $\mu g/m^3$				
	Degrees	Miles		N	$\bar{X}$	S	Min	Max
1	34	0.8	June through October 1969	74	0.0	1.6	–3.1	8.8
2	105	2.5	June through October 1969	88	–0.7	1.4	–5.3	1.4
3	112	0.4	June through October 1969	87	–0.6	1.6	–7.4	2.0
4	274	4.5	June through October 1969	85	0.0	0.7	–2.4	2.2
6	2	0.5	September through October 1969	34	0.8	0.8	–0.3	2.4

[a]Degrees are computed from north side of ASARCO stack in clockwise direction.

Nylon deterioration as measured by the Effects Network station[3] in East Helena indicated that a problem of acid aerosols might exist in East Helena. A network of additional nylon panel exposures was set out to determine the extent of the problem. Results from the 3-month exposure indicated that the problem was not sufficiently widespread or serious for further consideration. Only exposures within 1 mile of East Helena industry were affected.

NONSPECIFIC PARTICULATES

Total Suspended Particulates

Total suspended particulate matter was sampled by means of Electro Neutronics, Inc., samplers at five locations on a schedule that skipped every third day. The first four sampling locations were identical to the sampling locations of the continuous monitors. Sampling station 6 was added late in the study period to get particulate metal data from a point closer to the middle of the city of East Helena. The sampler was located in the immediate vicinity of the East Helena City Hall. Table 2-5 is a summary of the results. The sampling locations are identified by number, and location is given in miles and degrees from the smelter stack.

Settleable Particulates

Settleable particulate matter or dustfall was measured at five locations on a

Table 2-5. TOTAL SUSPENDED PARTICULATE SUMMARY STATISTICS

Station	Location[a]		Sampling period	Statistics, $\mu g/m^3$									
	Degrees	Miles		N	$\overline{X}$	$\overline{X}_g$	Min	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	Max
1	34	0.8	June through October 1969	76	108	91	14	29	63	112	147	178	241
2	105	2.5	June through October 1969	88	74	56	4	21	35	58	112	148	204
3	112	0.4	June through October 1969	87	59	47	1	17	33	56	76	99	181
4	274	4.5	June through October 1969	85	62	52	1	22	40	57	85	105	158
6	2	0.5	September through October 1969	34	166	136	26	44	88	167	232	276	360

[a] Degrees are computed from north side of ASARCO stack in clockwise direction.

monthly basis using 5-quart Tupperware canisters for samplers. These results are presented in Table 2-6. The highest dustfall results were measured at the East Helena City Hall sampling location. This location also had the highest measured suspended particulates.

Table 2-6. SETTLEABLE PARTICULATE RESULTS

Station	Location[a]		g/m^2–mo				
	Degrees	Miles	June	July	Aug	Sept	Oct
1	34	0.8	2	3	3	–	–
2	105	2.5	2	2	2	–	–
3	112	0.4	3	2	2	–	–
4	274	4.5	5	2	3	1	1
6	2	0.5	8	8	4	5	4

[a] Degrees are computed from north side of ASARCO stack in clockwise direction.

Windblown Particulates

Windbown particulates were collected using adhesive impactors (sticky paper) at 40 locations. This sampling was done in conjunction with the metal-fall collection. Because of the extended sampling period (1 and 2 months), the deposition rate results are not valid. Microscopic examination of these particulates, however, is valid and revealed that the particles were predominantly of natural origin. This indicates that if windblown particulates are a problem in this area, the principal causes are the semi-arid soil and unpaved streets.

Soiling Index

Soiling index was measured continuously at four locations on a 2-hour cycle using Unico 80 TS samplers. These results, which are summarized in Table 2-7, are low and do not warrant further consideration.

Table 2-7. SOILING INDEX SUMMARY STATISTICS, JULY THROUGH OCTOBER 1969

Station	Location[a]		Number of samples	% of time each station exceeded indicated Coh/10^3 lineal feet					
	Degrees	Miles		0	>0.2	>0.5	>1.0	>1.5	>2.0
1	34	0.8	1,831	64	24	7	1	0.2	0.06
2	105	2.5	1,466	96	2	0.3	–	–	–
3	112	0.4	1,646	100	-	–	–	–	–
4	274	4.5	1,686	97	3	1.6	0.5	0.3	0.06

[a] Degrees are computed from north side of ASARCO stack in clockwise direction.

METALLIC PARTICULATES

Four metals, arsenic, cadmium, lead, and zinc, are considered the most probable contaminants being emitted from East Helena industry. The suspended particulates and settleable particulate samples were analyzed for these metals. Because the glass-fiber filters were expected to distort the metal analyses, special samples were also taken on membrane filters. These samples were taken on a 72-hour basis in parallel with the standard 24-hour high-volume samples. At about 40 locations, settleable particulates were collected and analyzed. A 2.25-inch-diameter plastic container was used to collect these samples. The purpose of this sampling was to obtain information on the radial distribution of metals settling upon the ground. Samples were collected during August, September, and October 1969.

Arsenic

The study findings concerning arsenic are summarized in Table 2-8 and Figure 2-18.

Table 2-8. PARTICULATE ARSENIC SUMMARY

Station	1	2	3	4	6
Location	0.8 mi; 34°	2.5 mi; 105°	0.4 mi; 112°	4.5 mi; 274°	0.5 mi; 2°
	Settleable Particulates (mg/m² –mo)				
June	1.7	0.0	0.0	0.0	–
July	1.6	0.2	9.6	0.0	–
August	0.6	1.3	2.2	1.0	–
September	0.0	0.0	0.0	0.0	0.2
October	0.9	0.0	2.3	0.0	–
	Suspended Particulates on Membrane Filters (μg/100m³)				
N	28	25	23	8	–
$\overline{X}$	0.7	0.6	8.2	0.9	–
Maximum	2.0	2.0	40.0	1.0	–
Minimum	0.0	0.0	0.0	0.0	–

Table 2-8 (continued). PARTICULATE ARSENIC SUMMARY

Station	1	2	3	4	6
Location	0.8 mi; 34°	2.5 mi; 105°	0.4 mi; 112°	4.5 mi; 274°	0.5 mi; 2°
	Suspended Particulates on Glass-Fiber Filters ($\mu g/100m^3$)				
N	76	87	85	82	34
$\overline{X}$	0.6	1.1	6.0	0.5	8.4
Maximum	7.0	9.0	26.0	7.0	26.0
Minimum	0.0	0.0	0.0	0.0	0.0
>0 to <5	8	14	18	13	8
>5	3	8	40	2	22
>10	0	0	23	0	11
>20	0	0	1	0	1

The settleable particulate deposition rate of arsenic was greater in East Helena than in Helena. Sampling location 3, which is the closest to the industrial complex, has the highest values.

Of the samples taken on membrane filters, the highest values were measured at station 3. Three of the four sampling locations averaged less than 1 microgram of arsenic per 100 m^3. At site 3, the concentrations averaged 8.2, with a maximum of 40 μg per 100^3.

The samples collected on glass-fiber filters are in agreement with the membrane samples. Because of the shorter sampling time, the maximum values are somewhat higher. Results at sampling locations 3 and 6 show that nearness to the industrial complex causes higher values. Within a half mile of the stack, the concentration is elevated; however, beyond 1 mile, the concentration tends to level out.

Figure 2-18 shows the radial distribution of the rate of arsenic fallout. This distribution was obtained from the results of the metal-fall samples collected during September, October, and November.

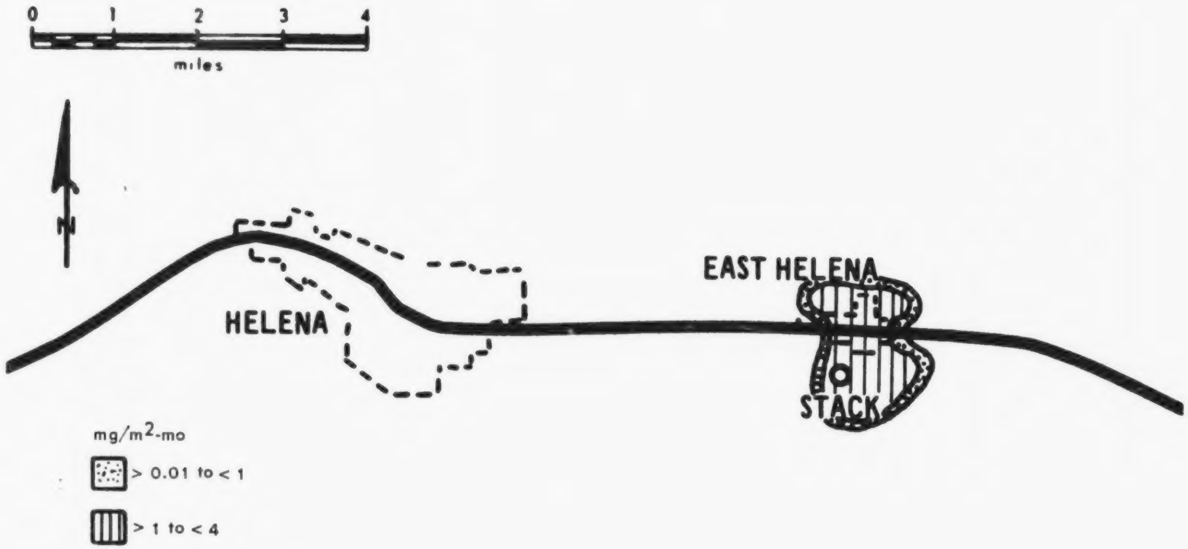

0
1
2
3
4
miles
N
HELENA
EAST HELENA
STACK
mg/m2-mo
> 0.01 to < 1
> 1 to < 4

Figure 2-18. Settleable particulate arsenic radial distribution.

Cadmium

The findings concerning cadmium are summarized in Table 2-9 and Figure 2-19.

The settleable particulate rate of cadmium deposition decreases with increasing distance from the East Helena industry. Sampling locations 3 and 6 had the highest values.

The samples on membrane filters and on glass-fiber filters are in general agreement with one another and with the settleable particulate samples, in that cadmium concentration increases with decreasing distance from the East Helena industrial complex. Sampling site 6, East Helena City Hall, had the most cadmium.

Table 2-9. PARTICULATE CADMIUM SUMMARY

Station	1	2	3	4	6
Location	0.8 mi; 34°	2.5 mi; 105°	0.4 mi; 112°	4.5 mi; 274°	0.5 mi; 2°
Settleable Particulates (mg/m^2–mo)					
June	0.0	0.0	2.0	0.1	–
July	0.5	0.1	3.0	0.1	–
August	0.2	0.1	1.6	0.1	–
September	0.5	0.3	1.2	0.2	2.2
October	0.5	0.4	1.5	0.2	3.2
Suspended Particulates on Membrane Filters ($\mu g/100m^3$)					
N	28	25	23	8	–
$\bar{X}$	2.3	1.4	6.7	0.6	–
Maximum	8	4	16	1	–
Minimum	0	0	0	0	–
Suspended Particulates on Glass-Fiber Filters ($\mu g/100m^3$)					
N	76	87	85	82	34
$\bar{X}$	6.1	2.5	10.2	2.9	29.4
Maximum	20	12	46	11	69
Minimum	2	0	0	1	1
>0 to <5	49	76	28	73	4
>5	27	6	56	9	30
>25	0	0	5	0	17
>50	0	0	0	0	7

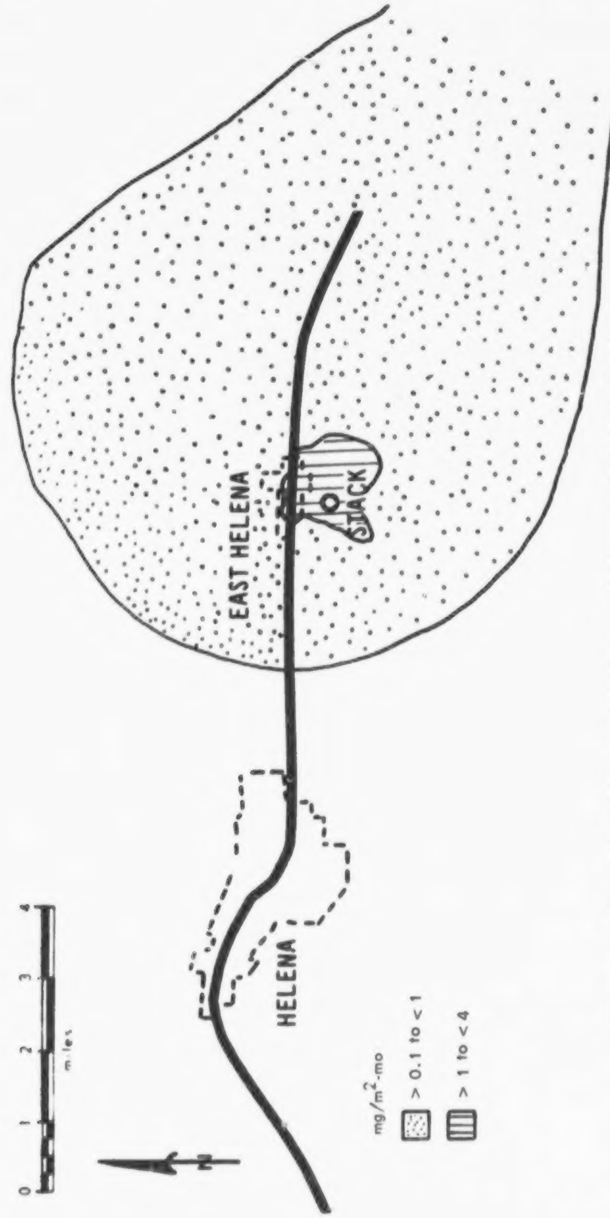

EAST HELENA
STACK
HELENA
N
0
1
2
3
4
miles
mg/m^2-mo
▨ > 0.1 to < 1
▥ > 1 to < 4

Figure 2-19. Settleable particulate cadmium radial distribution.

Cadmium

The findings concerning cadmium are summarized in Table 2-9 and Figure 2-19.

The settleable particulate rate of cadmium deposition decreases with increasing distance from the East Helena industry. Sampling locations 3 and 6 had the highest values.

The samples on membrane filters and on glass-fiber filters are in general agreement with one another and with the settleable particulate samples, in that cadmium concentration increases with decreasing distance from the East Helena industrial complex. Sampling site 6, East Helena City Hall, had the most cadmium.

Table 2-9. PARTICULATE CADMIUM SUMMARY

Station	1	2	3	4	6
Location	0.8 mi; 34°	2.5 mi; 105°	0.4 mi; 112°	4.5 mi; 274°	0.5 mi; 2°
Settleable Particulates (mg/m^2–mo)					
June	0.0	0.0	2.0	0.1	–
July	0.5	0.1	3.0	0.1	–
August	0.2	0.1	1.6	0.1	–
September	0.5	0.3	1.2	0.2	2.2
October	0.5	0.4	1.5	0.2	3.2
Suspended Particulates on Membrane Filters (μg/100m^3)					
N	28	25	23	8	–
$\bar{X}$	2.3	1.4	6.7	0.6	–
Maximum	8	4	16	1	–
Minimum	0	0	0	0	–
Suspended Particulates on Glass-Fiber Filters (μg/100m^3)					
N	76	87	85	82	34
$\bar{X}$	6.1	2.5	10.2	2.9	29.4
Maximum	20	12	46	11	69
Minimum	2	0	0	1	1
>0 to <5	49	76	28	73	4
>5	27	6	56	9	30
>25	0	0	5	0	17
>50	0	0	0	0	7

Figure 2-19 shows the spatial distribution of the deposition rate of cadmium on the area per month during the months of August through October. This distribution was obtained from the results of the 40 metal-fall samplers. Measurements indicate that 1 to 4 mg of cadmium per aquare meter of area was deposited on a 1.5-square-mile area around the East Helena industrial complex; 0.1 to 1 mg of cadmium per square meter of area was deposited over an area of about 60 square miles around East Helena.

Lead

The findings concerning lead are summarized in Table 2-10 and Figure 2-20.

Table 2-10. PARTICULATE LEAD SUMMARY

Station	1	2	3	4	6
Location	0.8 mi; 34°	2.5 mi; 105°	0.4 mi; 112°	4.5 mi; 274°	0.5 mi; 2°
Settleable Particulates (mg/m^2–mo)					
June	3	1	54	1	–
July	19	4	106	4	–
August	10	3	5	3	–
September	19	9	63	7	27
October	40	10	108	7	60
Suspended Particulates on Membrane Filters (μg/10m^3)					
N	28	25	23	8	–
$\bar{X}$	5.8	2.7	9.5	3.8	–
Maximum	11	8	18	6	–
Minimum	1	1	1	2	–
Suspended Particulates on Glass-Fiber Filters (μg/10m^3)					
N	76	87	85	82	34
$\bar{X}$	4.5	2.4	12.5	1.0	38.8
Maximum	53	25	160	7	150
Minimum	0	0	0	0	2
>0 to <10	69	78	55	54	9
>10	5	2	27	0	25
>50	1	0	4	0	10
>100	0	0	1	0	4

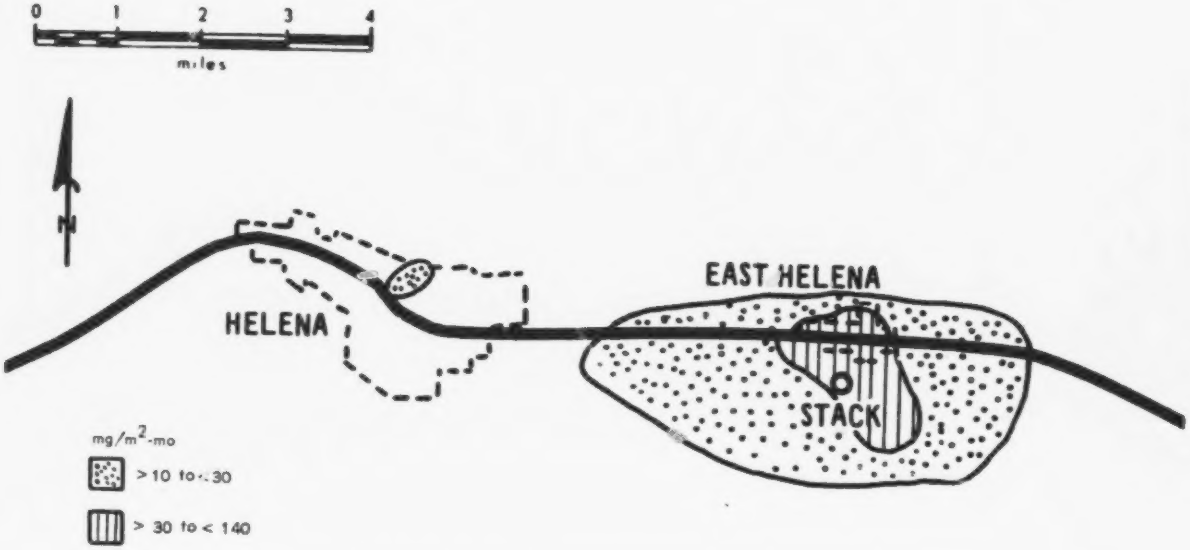

0
1
2
3
4
miles
N
HELENA
EAST HELENA
STACK
mg/m²-mo
▨ > 10 to < 30
▥ > 30 to < 140

Figure 2-20. Settleable particulate lead radial distribution.

The settleable particulate deposition rate of lead increases dramatically in the proximity of the East Helena industrial complex. At station 3, as much as 625 pounds of lead per square mile was deposited during the month of October. During the same month, 350 pounds of lead per square mile was deposited in the vicinity of East Helena City Hall. In Helena, 40 pounds of lead per square mile was deposited during the same month.

The suspended particulate samples, collected on glass-fiber filters and on membrane filters, and the settleable particulate samples are in agreement in that the lead content increases with decreasing distance from the East Helena industrial complex. At station 3 the lead concentration averaged about 1 microgram per cubic meter. At station 6, East Helena City Hall, the suspended particulates averaged about 4 micrograms of lead per cubic meter, with values ranging up to 15. The concentration in Helena averaged 0.1, with individual values ranging up to 0.7 microgram of lead per cubic meter. The people in East Helena (stations 1 and 6) are exposed to between 0.5 and 4 micrograms per cubic meter, with individual daily doses up to 15 micrograms per cubic meter.

Figure 2-20 shows the radial distribution of the deposition rate of lead. This distribution was obtained from the results of the metal-fall samples. Measurements indicate that 30 to 140 milligrams of lead per square meter per month is deposited on about 2 square miles of area around East Helena; 10 to 30 milligrams of lead per square meter per month is deposited on about 8 square miles of area around East Helena.

Zinc

The findings concerning zinc are summarized in Table 2-11 and Figure 2-21.

The settleable particulate deposition rate of zinc increases dramatically in the proximity of the East Helena industrial complex. The highest values were obtained at the East Helena City Hall sampling site (station 6). This sampling location is the nearest to the Anaconda Company and American Chemet, both of which process zinc oxide.

The total suspended particulate samples collected on glass-fiber filters and on membrane filters agree reasonably well. Because of the zinc content of the glass-fiber filters, it was possible to measure zinc only to the nearest microgram per cubic meter. Zinc content was measured to the nearest tenth of a microgram per cubic meter on the membrane filter samples. The East Helena City Hall sampling site had the highest values; the average was about 3 micrograms per cubic meter, with daily values ranging up to 8 micrograms per cubic meter.

Figure 2-21 shows the spatial distribution of the deposition rate of zinc on the area. This distribution was obtained from the results of the metal-fall samples. Measurements indicate that 30 to 90 milligrams of zinc per square meter per month are deposited on about 1.5 square miles of area around East Helena; 10 to 30 milligrams of zinc per square meter per month are deposited on about 8 square miles of area around East Helena. The figure also shows other areas with such a rate of deposition; however, these areas are defined by single samples and should not be considered significant. The deposition rate in the remaining Helena Valley (about 60 square miles) could be considered to average nearly 5 milligrams of zinc per square meter per month.

Table 2-11. **PARTICULATE ZINC SUMMARY**

Station	1	2	3	4	6
Location	0.8 mi; 34°	2.5 mi; 34°	0.4 mi; 112°	4.5 mi; 274°	0.5 mi; 2°
Settleable Particulates (mg/m^2 –mo)					
June	5	3	29	9	–
July	13	4	29	5	–
August	7	2	26	2	–
September	12	1	13	5	82
October	6	3	7	2	71
Suspended Particulates on Membrane Filters ($\mu g/10m^3$)					
N	28	25	23	8	–
$\overline{X}$	6.4	2.5	7.6	1.8	–
Maximum	14	5	21	3	–
Minimum	2	1	1	1	–
Suspended Particulates on Glass-Fiber Filters ($\mu g/m^3$)					
N	76	87	83	82	34
$\overline{X}$	0.3	0.1	0.6	0.0	3.3
Maximum	3	1	4	1	8
Minimum	0	0	0	0	0
>0 to <2	18	4	27	1	7
>2	1	0	5	0	13
>5	0	0	0	0	7

OZONE AND NITROGEN DIOXIDE

Limited ozone and nitrogen dioxide measurements were made in conjunction with the vegetation effects studies.

Ozone

A Mast Ozone Meter ran continuously at sampling location 1 (East Helena–

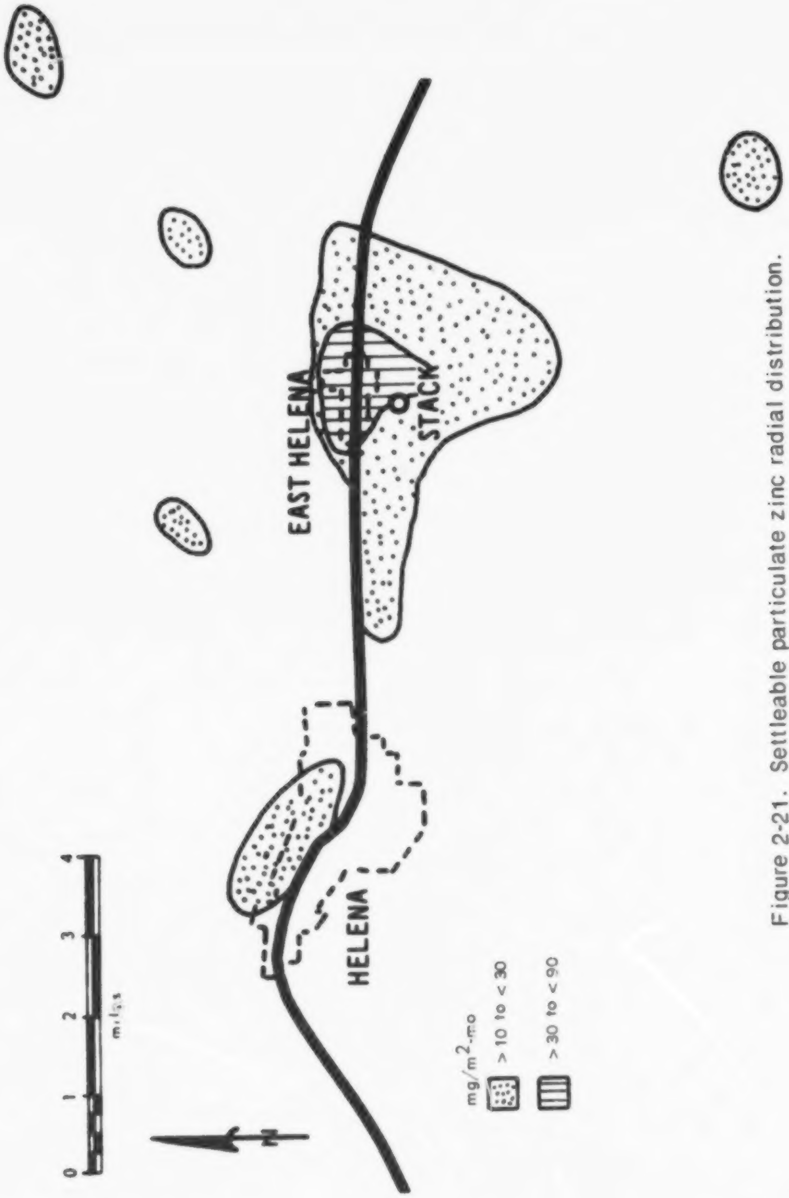

EAST HELENA
STACK
HELENA
0
1
2
3
4
miles
N
mg/m^2-mo
> 10 to < 30
> 30 to < 90

Figure 2-21. Settleable particulate zinc radial distribution.

Prickly Pear Street) from June 14 to September 9, and at sampling location 3 (Vollmer's Ranch) from September 9 to September 22. The instrument indicated that the concentration of ozone varied at both sampling locations between 0.03 and 0.04 ppm. The instrument recorded 0 ppm during the episode fumigations by sulfur dioxide.

Nitrogen Dioxide

A Beckman portable nitrogen dioxide analyzer, Model K1008, ran continuously at sampling location 3 (Vollmer's Ranch) from October 5 to October 12, 1969. During that time the instrument failed to detect nitrogen dioxide. The sensitivity of the instrument as used was estimated to be 0.01 ppm.

REFERENCES FOR CHAPTER 2

1. Huey, N. A. The Lead Dioxide Estimation of Sulfur Dioxide Pollution. JAPCA, *18*(9):610-611, September 1968.

2. Huey, N. A., M. A. Waller, and Charles Robson. Field Evaluation of an Improved Sulfation Measurement System. Paper No. 69-133; presented at 62nd Annual Meeting of the Air Pollution Control Association. June 22-26, 1969.

3. Cavender, James et al. Interstate Surveillance Project: Measurement of Air Pollution Using Static Monitors. U.S. Environmental Protection Agency, Office of Air Programs. Publication No. APTD-0666. Research Triangle Park, N.C. 27711. 1971.

3. SURVEY OF WATER QUALITY

Albert V. Soukup
ENVIRONMENTAL PROTECTION AGENCY
Office of Water Programs

INTRODUCTION

As part of the Helena Valley Area Environmental Pollution Study, the Bureau of Water Hygiene, Public Health Service, Region VIII, was requested to ascertain the chemical constituents of all drinking and irrigation waters in the area, analyze the data, and prepare a report.

TYPES OF WATER SUPPLIES

In the Valley both surface and ground waters are used by the public. The city of Helena obtains some of its water from a surface supply located northeast of East Helena. This water receives conventional treatment that includes filtration at a water plant located north of East Helena. The remaining water supply is obtained from an area near the west end of the city, which should not be influenced by air pollution in the Valley. East Helena obtains its water from a well field located north of the city and from a surface supply 2.5 miles south-southeast of the city, McClellan Creek. Chlorination of the waters is the only treatment provided.

SAMPLING

Water samples were collected on July 1, 1969, October 25, 1969, and April 4, 1970. On July 1, samples were collected from six locations. These samples are considered typical of the area's water supply, and they served as screening portions. The locations were selected after taking into consideration the topography and prevailing wind directions. The samples collected on October 25, 1969, were meant to be from the same locations; however, because of adverse climatic conditions, samples could not be obtained at two of the sites representative of the East Helena city water supply. Accordingly, East Helena city tap water was sampled. On April 4, 1970, three water samples were taken. These samples were from the two different city water sources and from Prickly Pear Creek.

Sampling Locations

1. Residence of Ray Gustafson, ground-water sample from a 32-foot well. Location SE1/4, Sec 28 T9N, R2W (about 6 miles SSE of East Helena).
2. McClellan Creek, surface water, upstream of the East Helena intake, SE1/4, Sec 32 T9N, R2W (about 6 miles south of East Helena).
3. Helena Water Plant intake, surface water, NE1/4, Sec 17, T1ON, R2W (about 3 miles NE of East Helena).
4. East Helena city well supply, NE1/4, Sec 23, T1ON, R3W (about 1.5 miles NW of East Helena).
5. East Helena Surface Water Reservoir, McClellan Creek supply, NW1/4, Sec 17, T9N, (about 2.5 miles SSE of East Helena).
6. Prickly Pear Creek, surface water, SE1/4, Sec 15, T1ON, R3W (about 2.5 miles NW of East Helena).
7. East Helena city tap, center of town.

LABORATORY METHODS

The 1-gallon samples of water from each sampling location were air-mailed to the Cincinnati, Ohio, laboratory of the Public Health Service. The analytical methods used were those specified in *Standard Methods for the Examination of Water and Wastewater,* American Public Health Association, current edition, and other approved methods in a few instances.

RESULTS

All samples were analyzed for the following: arsenic, cadmium, lead, zinc, iron, manganese, sulfate, fluoride, chromium, silver, copper, cobalt, nickel, chloride, nitrate, boron, cyanide, selenium, pH, specific conductance, turbidity, color, and total dissolved solids. Analyses of the first seven components were found to give pertinent information to the study. These results are reported in Table 3-1.

DISCUSSION OF RESULTS

Samples from sampling locations 1 and 2 can be considered control samples since they are the most distant from the East Helena smelting complex. It should be noted, however, that these two sampling locations are downwind and may, therefore, be influenced by airborne pollutants. Sampling location 3 is related to the Helena city water supply. Since samples from location 6 are from Prickly Pear Creek, these may be expected to be influenced by water runoff from the

Table 3-1. WATER QUALITY ANALYTICAL RESULTS

(mg/1)

Sampling location	Sampling date	As	Cd	Pb	Zn	Fe	Mn	SO_4
1	7/1/69	0	0.002	0.027	–	0.080	0.013	29
	10/25/69	<0.007	0	0	0.092	0.018	0.004	31
2	7/1/69	0	0	0.010	0.012	0.152	0.018	15
	10/25/69	<0.007	0	0	0.004	0.012	0	17
3	7/1/69	0	0	0.033	0.016	0.146	0.025	41
	10/25/69	0.020	0	0	0.003	0.037	0.007	33
	4/4/70	0.017	0.003	0.019	0.007	0.023	0.013	32
4	7/1/69	0	0	0.010	0.032	0.015	0	54
5	7/1/69	0	0	0	0.012	0.153	0.009	17
6	7/1/69	<0.030	0.006	0.044	0.164	0.800	0.160	30
	10/25/69	0.007	0.001	0	0.056	0.036	0.007	52
	4/4/70	0.014	0.007	0.042	0.070	0.320	0.051	52
7	10/25/69	0.007	0	0	0.025	0.023	–	21
	4/4/70	<0.01	0	0.012	0.016	0.016	0.002	26
Recommended DWS[a]		0.010	–	–	5.000	0.300	0.050	250
Mandatory limits of DWS		0.050	0.010	0.050	–	–	–	–

[a] DWS= drinking water standards.

smelter complex and from the large slag piles. Sampling locations 4, 5, and 7 are related to the East Helena city water supply.

The chemical constituents determined did not exceed the mandatory limits of the Public Health Service Drinking Water Standards. The sulfate results show that there is no contamination by sulfur dioxide. The water in Prickly Pear Creek contains elevated levels of arsenic, cadmium, lead, zinc, iron, and manganese. The water at the Helena city water intake has elevated levels of arsenic, lead, and manganese.

SUMMARY

The smelting complex in East Helena is contributing measurable amounts of arsenic, cadmium, lead, zinc, iron, and manganese to the surface water in the Helena Valley. These amounts do not exceed the mandatory limits of the Public Health Drinking Water Standards. On the basis of these investigations, the water quality appears to be satisfactory from a public health standpoint. No bacteriological or radiochemical analyses were made.

4. ABUNDANCE AND DISTRIBUTION OF LEAD, ZINC, CADMIUM, AND ARSENIC IN SOILS

A. T. Miesch and Claude Huffman, Jr.
DEPARTMENT OF INTERIOR
U.S. Geological Survey

INTRODUCTION

An investigation of the abundance and distribution of lead, zinc, cadmium, and arsenic in soils of the Helena Valley area of Montana was undertaken. The purpose of the investigation was to determine the extent of contamination of the soils by emissions from the smelter operation in East Helena.

CHARACTER OF SOILS

The soils of the Helena Valley are developed largely on valley fill derived from surrounding mountain ranges, and on lake sediments of Tertiary age. They are composed predominantly of silt and clay, are moderately calcareous, and have only small organic contents. The soils formed on valley fill contain abundant rock fragments, and soil profiles are only poorly to moderately developed. The rock fragments are extremely diverse in type, reflecting the diverse geology of the mountains nearby. None of the rock fragments are of a type containing unusual amounts of lead, zinc, cadmium, or arsenic. In areas where the soil has been cultivated, most of the rock fragments have been removed.

Soil profiles on the lake sediments of Tertiary age are also poorly to moderately developed. The lake sediments in the Canyon Ferry Lake area, immediately east of the Helena Valley, have been described by Mertie, Fischer, and Hobbs.[1] Most of the sediments are rich in tuffaceous materials of volcanic origin. The lake sediments in the study area are confined largely to the southeastern part of the Helena Valley.[2]

SAMPLING

Soil samples are collected at a confined spot, but are intended to represent the soils of the vicinity. If the soils in the vicinity are uniform in composition, little or no sampling error is expected. If, however, the soils in the vicinity are highly variable in composition, as is commonly the case, large sampling errors can result. A sampling locality, or site, was formally defined in this study as a

Preceding page blank

circular area 100 feet in diameter; samples were taken within localities using randomization procedures. Duplicate samples were taken to measure variability within localities and, therefore, the magnitude of sampling error. Duplicate chemical analyses were made of randomly selected samples to determine the analytical precision or the magnitude of laboratory error.

In view of the fact that the purpose of this study was to assess the magnitude of lead, zinc, cadmium, and arsenic contamination from the smelter operation in East Helena, as reflected in the soils, the sampling localities were placed strategically for this purpose.

Eight sampling sites were placed along a straight line (traverse A) extending east-southeast from the main smelter stack in East Helena. The first site was at a distance of 0.67 mile from the stack; subsequent sites were placed at geometrically increasing distances of 1, 1.5, 2.25, 3.37, 5.062, 7.5, and 11 miles as shown in Figure 4-1 (each distance is approximately 1.5 times greater than the previous one). All of the sampling localities were within cultivated fields.

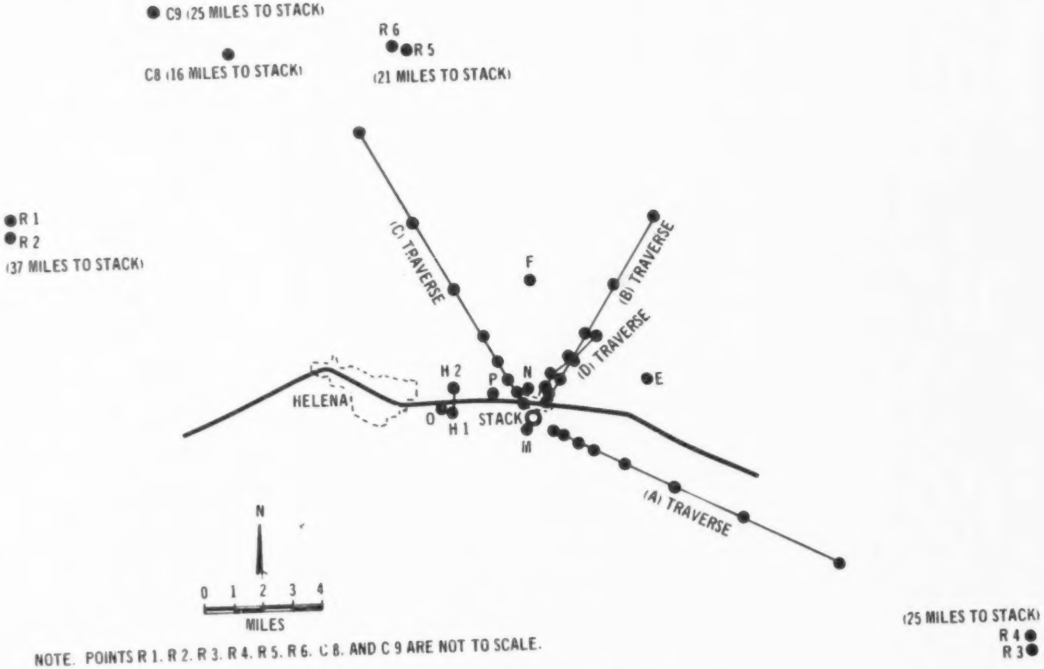
Seven other sampling sites were placed along a straight line (traverse B) extending approximately north-northeast from the smelter stack, spaced at distances of from 0.67 to 7.5 miles from the stack, as was done along traverse A. The sites were all within cultivated fields.

Ten additional sampling sites were placed along a line (traverse C) extending generally northwest from the stack. These also were spaced at geometrically increasing distances from the stack, as in traverses A and B. The site nearest the stack was at a distance of 0.67 mile; the most distant site, C9, was 25 miles from the stack. The eight sites nearest the stack were within cultivated fields, whereas sites C8 and C9 were in areas that may never have been under cultivation.

Four sampling sites were placed along an irrigation ditch (traverse D) that extends generally northeastward from East Helena in the vicinity of traverse B. All samples from these localities were taken near the ditch, in places unlikely to have been cultivated or fertilized for some years. The ditch has been there for at least 20 years since it is represented on a topographic map of the East Helena quadrangle published by the U.S. Geological Survey in 1950. The sites are spaced at distances of 1, 1.5, 2.25, and 3.375 miles from the smelter stack.

Two sampling sites, E and F (Figure 4-1), were placed at a distance of 4.5 miles from the stack; site E was between traverses A and B, and site F was between traverses B and C.

Six sampling sites were placed in areas remote from East Helena, outside of the Helena Valley. Two of these, R1 and R2, were west of the Continental Divide, about 10 miles north of the town of Avon. Two others, R3 and R4, were east of Canyon Ferry Lake, about 8 miles northeast of Townsend. The other two, R5 and R6, were on the north side of Rattlesnake Mountain and about 20 miles north of Helena. The soils in the Canyon Ferry Lake area developed on lake sediments of Tertiary age, similar to those in the Helena Valley. The soils north of Avon and those north of Rattlesnake Mountain are developed on valley


C9 (25 MILES TO STACK)
C8 (16 MILES TO STACK)
R 6
R 5
(21 MILES TO STACK)
R 1
R 2
(37 MILES TO STACK)
(C) TRAVERSE
F
(B) TRAVERSE
(D) TRAVERSE
E
H 2
P
N
HELENA
O
H 1
STACK
M
(A) TRAVERSE
N
0 1 2 3 4
MILES
(25 MILES TO STACK)
R 4
R 3

NOTE. POINTS R 1. R 2. R 3. R 4. R 5. R 6. C 8. AND C 9 ARE NOT TO SCALE.

Figure 4-1. Sampling locations.

fill. All samples collected outside the Helena Valley were from uncultivated fields.

A single site, M, was located in a cultivated field about 1000 feet southwest of the smelter stack.

The sampling procedure at each of the sites referred to above (except those along traverse D) was as follows. by use of rectangular coordinates and a table of random numbers, two random points were located within each site–the site, as mentioned previously, was defined as a circular area 100 feet in diameter. At each point, one sample was taken from the upper 4 inches of soil (within the plow zone in cultivated areas) and another was taken at a depth of 6 to 10 inches (generally below the plow zone). Thus, four samples were taken from each site. The samples were taken with a small spade, and care was taken to avoid soil that had touched the spade itself. Each sample consisted of about 100 grams and was stored in a paper envelope until received in the laboratory.

Samples collected along the irrigation ditch in traverse D were taken from depths of from 0 to 1 inch, 2 to 4 inches, and 6 to 10 inches

A number of other samples and sample sets were taken for special purposes. Among these was a set of five soil samples collected at site H1, immediately north of U.S. Highway 12 and about 2 miles west of East Helena; this set was for use in a search for significant highway contamination effects. The samples were collected at distances of 5, 10, 20, 40, and 80 feet from the pavement. Another set of five soil samples was collected at site H2, about 1000 feet north of site H1 and on the north side of the tracks of the Northern Pacific Railroad. The samples were collected at distances of 5, 10, 20, 40, and 80 feet from the tracks. The three samples taken from nearest the tracks were of fill material that forms the track bed. All samples in the series H1 and H2 were collected from the upper 1-inch layer.

Two additional samples were taken of the upper 4-inch soil layer at site N, and samples of siltstone of the Belt Series of Precambrian age and of tuffaceous sediments of Tertiary age were collected at sites O and P, respectively.

LABORATORY METHODS

A total of 176 samples was collected in this study. Twenty-one of these, selected at random, were homogenized and split once in a Jones splitter constructed of aluminum, yielding 197 samples for laboratory analysis. The 197 samples were assigned new sample numbers and analyzed in randomized sequence; neither the locations from which the samples were taken nor the duplicate splits were known to the analyst.

Sample preparation prior to laboratory analysis consisted of passing the samples through a jaw crusher to reduce rock fragments present in some of them and grinding through ceramic plates set to -100 mesh.

Lead and zinc contents were determined by an atomic absorption technique developed by Huffman and J. A. Thomas.[3] A 1-gram sample is placed in a 150-ml beaker and moistened with about 10 ml of water. Ten ml of HNO_3 is added, and the beaker is covered with a watch glass. The solution is then boiled on a shaking hotplate until the volume is reduced to about 7 ml. It is then cooled and the sides of the beaker are washed down with about 25 ml of water. The beaker is covered with a watch glass again and placed on a steam bath for 30 minutes. The solution is then cooled, transferred to a 50-ml volumetric flask, diluted to volume, and mixed. The flask is then allowed to stand for several hours to permit the insoluble residue to settle. A portion of this solution is then atomized into the flame of the atomic absorption instrument for the determination of lead. Ten ml of this solution (1 gram in 50 ml) is diluted to 50 ml volume for the zinc determination. A few of the samples, high in lead or zinc, required additional dilutions. Table 4-1 gives the instrumental parameters used.

Table 4-1. INSTRUMENTAL PARAMETERS FOR DETERMINING LEAD AND ZINC CONTENT OF SOIL

Parameters	Lead	Zinc
Instrument	P. E. model 303	P. E. model 303
Wavelength	2836 Å	2138 Å
Source	Hollow cathode	Hollow cathode
Burner	Laminar	Laminar
Flame	Air-acetylene	Air-acetylene
Flame condition	Oxidizing	Oxidizing
Slit	4	4
Scale	X-5 or X-1	X-2 or X-1

The 2836 Å wavelength line was selected for the determination of lead because calcium interfered at the more sensitive 2170 Å line. Little or no interference was noted at the 2836 Å line.

Cadmium was determined by an atomic absorption method, described by Nakagawa and Harms,[4] after some modification in the sample digestion procedure. One-gram samples were boiled in 5 ml of HNO_3 and then diluted to 20 ml, rather than 10 ml, to reduce the possibility of calcium interference.

Ten samples, selected randomly from the total 197, were digested in HF (and HNO_3 and $HClO_4$) using a procedure described by Huffman[5] and reanalyzed for lead, zinc, and cadmium by atomic absorption procedures. The HF digestion is more complete than that achieved using boiling HNO_3, but the differences were judged insignificant for the purposes of this investigation. The lead, zinc, and cadmium not extracted by boiling HNO_3 are possibly contained in stable silicate and oxide minerals that commonly occur as natural soil components.

Arsenic was determined by a modified Gutzeit method described by Ward et al.[6] This method, specifically for determining arsenic in soils, is a confined-spot procedure using a modified Gutzeit apparatus in which, by the action of zinc in hydrochloric acid solution, arsenic III is reduced to arsine (AsH_3) gas, which reacts with mercuric chloride to form a yellow-to-orange compound. Artificial standards, corresponding to known arsenic concentrations, are used to estimate the concentrations of arsenic in the unknowns. Rather than digestion of the sample after fusion with potassium hydroxide,[6] digestion was accomplished by boiling first in HNO_3 and then in HCl. The arsenic in the sample, therefore, was oxidized by HNO_3, and excess HNO_3 was destroyed by boiling in HCl before adding the zinc.

Evaluation of Errors Due to Sampling and Laboratory Analysis

Two sources of error are regarded as important in this investigation. One of these is the variability of soils within sampling localities. Because of this variability, individual samples or pairs of samples do not represent precisely the localities from which they were taken – that is, no single sample has the composition of the sampling locality as a whole, and neither does the average of any sample pair. A second source of error is the variability in laboratory analysis; the same sample subjected to repeated analysis yields a spread of analytical values. No single analysis or no average analysis can be expected to correspond exactly to the true concentration of the element in the sample analyzed.

Estimates of the total experimental error, due to both sampling and laboratory analysis, were obtained for each element by comparing the analytical results on duplicate samples from 33 sampling sites. Within each locality, one duplicate pair was obtained from the upper 4 inches of soil, and one was obtained from the depth of 6 to 10 inches, yielding a total of 66 pairs. Pairs were not used in the error estimates, however, if the element was not detected in one or both samples of the pair. Thus, 41 pairs were used in the estimate of total experimental error in lead, 66 pairs were used for zinc, 62 pairs were used for cadmium, and 40 pairs were used for arsenic. The estimates of total experimental error for each element, expressed as logarithmic variance and as geometric error, are listed in Table 4-2. The geometric error, which is the antilogarithm of the square root of the log variance, may be used to determine the expected range for the correct value for a sampling locality from an individual analysis. The expected range, with a confidence of 68 percent, is from the analytical value divided by the geometric error to the analytical value times the geometric error. For example, if the analytical value for lead is 100 parts per million, the correct value for the sampling locality is expected to be in the range 67 (=100/1.49) to 149 (=100x1.49) parts per million.

Table 4-2. ESTIMATES OF EXPERIMENTAL ERROR

Element	Log variance	Geometric error
Lead	0.0303	1.49
Zinc	0.0039	1.16
Cadmium	0.0223	1.41
Arsenic	0.0230	1.42

The relative importances of the two sources of error, sampling and laboratory analysis, have been estimated using the duplicate analyses of the 21 randomly selected samples referred to previously. These estimates, again expressed as logarithmic variances, are given in Table 4-3. Thus, sampling and laboratory analysis are estimated to be about equally important sources of error in the data on arsenic, but sampling is the dominant source of error in the data on lead, zinc, and cadmium. More precise laboratory methods would not significantly improve the quality of the data.

Table 4-3. ESTIMATED RELATIVE IMPORTANCE OF ERRORS IN SAMPLING AND LABORATORY ANALYSIS

Source of error	Lead	Zinc	Cadmium	Arsenic
Sampling	0.0247 (82%)	0.0028 (71%)	0.0147 (66%)	0.0098 (43%)
Laboratory analysis	0.0056 (18%)	0.0011 (29%)	0.0076 (34%)	0.0132 (57%)
Total error	0.0303	0.0039	0.0223	0.0230

Since two samples were collected from each depth zone in each locality, each depth zone in each locality can be represented by an average of two values. The error variances of the averages representing each locality are one-half those given above, but the relative importances of the sources of error are the same. The sampling error could be reduced to any desired level in future studies of this kind by collecting a larger number of samples in each locality.

DISCUSSION OF RESULTS

Graphs showing the metal contents of soils, in parts per million, as a function of distance of the sampling localities from the smelter stack, in miles, are nonlinear on arithmetic scales, and individual data points exhibit large amounts of scatter about the curved regression lines. The large scatter results in part from the proportionate nature of the error in the analytical data: the expected error in an analysis is approximately proportional to the amount of the element present in the sample.

These difficulties are partially resolved by plotting the logarithm of the analytical determination against the logarithm of the distance of the sampling locality from the smelter stack. Lead, zinc, cadmium, and arsenic contents of the soils decrease systematically with distance from the smelter stack. The systematic decrease is generally linear on the log-log scales, and the scatter of points about the regression lines is homogeneous – that is, independent of the magnitude of the analytical values. In some cases, the linearity of the relationships and the goodness of fit are remarkable. Results are presented in Table 4-4. Coefficients of determination (squares of the coefficients of correlation between log metal content and log distance from the stack) range up to 0.99, indicating that up to 99 percent of the variance in metal content is statistically associated with distance from the smelter stack.

Table 4-4. SOIL METAL CONTENT AS FUNCTION OF DISTANCE FROM SMELTER

Traverse	Depth, in.	Regression equation	Coefficient of determination
A	0 to 4	$\log \mathrm{Pb} = 2.9115 - 1.4466 \log D$	0.987
A	6 to 10	$\log \mathrm{Pb} = 2.2962 - 1.0910 \log D$	0.713
B	0 to 4	$\log \mathrm{Pb} = 2.8520 - 1.5244 \log D$	0.908
B	6 to 10	$\log \mathrm{Pb} = 1.5370 - 0.6251 \log D$	0.253
C	0 to 4	$\log \mathrm{Pb} = 2.6831 - 1.2952 \log D$	0.819
C	6 to 10	$\log \mathrm{Pb} = 1.6890 - 0.4561 \log D$	0.361
D	0 to 1	$\log \mathrm{Pb} = 3.6058 - 2.6996 \log D$	0.900
D	2 to 4	$\log \mathrm{Pb} = 2.6897 - 2.1421 \log D$	0.404
D	6 to 10	$\log \mathrm{Pb} = 1.8679 - 0.0592 \log D$	0.104
A	0 to 4	$\log \mathrm{Zn} = 2.3109 - 0.5878 \log D$	0.901
A	6 to 10	$\log \mathrm{Zn} = 2.0294 - 0.3045 \log D$	0.622
B	0 to 4	$\log \mathrm{Zn} = 2.3854 - 0.8923 \log D$	0.935
B	6 to 10	$\log \mathrm{Zn} = 1.9545 - 0.4010 \log D$	0.655
C	0 to 4	$\log \mathrm{Zn} = 2.6520 - 0.8183 \log D$	0.607
C	6 to 10	$\log \mathrm{Zn} = 1.9505 - 0.1441 \log D$	0.167
D	0 to 1	$\log \mathrm{Zn} = 3.0525 - 2.2717 \log D$	0.899
D	2 to 4	$\log \mathrm{Zn} = 3.0021 - 2.5064 \log D$	0.804
D	6 to 10	$\log \mathrm{Zn} = 2.3325 - 1.3452 \log D$	0.498
A	0 to 4	$\log \mathrm{Cd} = 1.4226 - 1.3571 \log D$	0.994
A	6 to 10	$\log \mathrm{Cd} = 0.7470 - 0.8342 \log D$	0.688
B	0 to 4	$\log \mathrm{Cd} = 1.3547 - 1.4541 \log D$	0.973
B	6 to 10	$\log \mathrm{Cd} = 0.1951 - 0.4069 \log D$	0.368
C	0 to 4	$\log \mathrm{Cd} = 1.1322 - 1.0770 \log D$	0.752
C	6 to 10	$\log \mathrm{Cd} = 0.2717 - 0.4362 \log D$	0.450
D	0 to 1	$\log \mathrm{Cd} = 1.8347 - 2.0268 \log D$	0.871
D	2 to 4	$\log \mathrm{Cd} = 1.4839 - 2.1642 \log D$	0.765
D	6 to 10	$\log \mathrm{Cd} = 0.4257 - 0.6867 \log D$	0.120
A	0 to 4	$\log \mathrm{As} = 1.7133 - 0.7211 \log D$	0.674
A	6 to 10	$\log \mathrm{As} = 1.4920 - 0.6656 \log D$	0.675
B	0 to 4	$\log \mathrm{As} = 1.6788 - 1.0270 \log D$	0.636
B	6 to 10	$\log \mathrm{As} = 0.9773 - 0.3459 \log D$	0.120
C	0 to 4	$\log \mathrm{As} = 1.3910 - 0.6162 \log D$	0.368
C	6 to 10	$\log \mathrm{As} = 1.1169 - 0.3145 \log D$	0.176
D	0 to 1	$\log \mathrm{As} = 2.1605 - 2.6582 \log D$	0.681
D	2 to 4	$\log \mathrm{As} = 1.7249 - 2.1320 \log D$	0.586
D	6 to 10	$\log \mathrm{As} = 1.1244 - 0.6483 \log D$	0.143

The expected metal contents of soils at varying distances from the stack, as determined from the regression equations, are summarized in Tables 4-5 and 4-6.

Table 4-5. EXPECTED LEAD, ZINC, CADMIUM, AND ARSENIC CONTENTS OF CULTIVATED SOILS ALONG TRAVERSES A, B, AND C

Traverse	Direction from smelter stack	Concentration (ppm) at indicated distance from stack, mi			
		1	2	4	8
Lead in upper 4-inch soil layer					
A	ESE	820	300	110	40
B	NNE	710	250	86	30
C	NW	480	200	80	32
Lead in soils at depth of 6 to 10 inches					
A	ESE	200	93	44	20
B	NNE	34	22	14	9
C	NW	49	36	26	19
Zinc in upper 4-inch soil layer					
A	ESE	210	140	91	60
B	NNE	240	130	70	38
C	NW	450	250	140	82
Zinc in soils at depth of 6 to 10 inches					
A	ESE	110	87	70	57
B	NNE	90	68	52	39
C	NW	89	31	73	66
Cadmium in upper 4-inch soil layer					
A	ESE	26	13	4	2
B	NNE	22	8	3	1
C	NW	14	6	3	1
Cadmium in soils at depth of 6 to 10 inches					
A	ESE	6	3	2	1
B	NNE	2	1	1	0.7
C	NW	2	1	1	0.8
Arsenic in upper 4-inch soil layer					
A	ESE	52	31	19	12
B	NNE	48	23	11	6
C	NW	25	16	10	7
Arsenic in soils at depth of 6 to 10 inches					
A	ESE	31	20	12	8
B	NNE	9	7	6	5
C	NW	13	10	9	7

Table 4-6. EXPECTED LEAD, ZINC, CADMIUM, AND ARSENIC CONTENTS OF UNCULTIVATED SOILS ALONG TRAVERSE D

Element	Depth of soil, in.	Concentration (ppm) at indicated distance from stack, mi		
		1	2	4
Lead	0 to 1	4000	620	96
	2 to 4	490	110	25
	6 to 10	74	71	68
Zinc	0 to 1	1100	230	48
	2 to 4	1000	177	31
	6 to 10	210	85	33
Cadmium	0 to 1	68	17	4
	2 to 4	30	7	2
	6 to 10	3	2	1
Arsenic	0 to 1	140	23	4
	2 to 4	53	12	3
	6 to 10	13	9	5

Lead

The geometric mean concentration of lead in soils of the United States is given by Shacklette, Hamilton, Boerngen, and Bowles as 16 ppm;[7] the geometric deviation is 1.96. Thus, 95 percent of the soils of the United States are estimated to have lead contents in the range from 4 ($16/1.96^2$) to 61 (16×1.96^2) ppm. The geometric mean lead content of surface soils collected in this investigation in areas remote from the Helena Valley is 15 ppm, close to the average for soils of the United States. The geometric mean lead content of soils collected at a depth of 6 to 10 inches in the remote areas is slightly lower, 9 ppm.

The frequency distributions of lead are censored at 20 ppm. The mean logarithms were estimated using a technique described by Cohen[8] and Miesch.[9]

Soils distant from the smelter in East Helena, but of the same type as those near the smelter, therefore, are not at all extraordinary in the amounts of lead they contain.

Samples of soil collected from the upper 4-inch soil layer within a mile of the smelter stack commonly contain more than 1000 ppm lead, and 500 to 800 ppm appears to be about the average at a distance of 1 mile. One sample collected from the upper 1 inch of the soil layer along the irrigation ditch north of East Helena contained 6500 ppm lead. Two other samples collected 0.67 mile northwest of the stack contained 4500 and 6800 ppm lead.

The lead content of the upper 4-inch soil layer decreases progressively away from the stack for a distance of 10 to 15 miles. Beyond that distance, the lead content of the upper 4-inch soil layer is about the same as that of soils outside the Helena Valley. Both the lead content of the upper 4-inch soil layer and the correlation of lead content with distance from the stack appear to be related to wind direction frequency as reported by the Montana State Department of Health. A wind direction toward the ESE, the direction of traverse A from the stack, is 5 to 7 times more frequent than toward the NNE or NW, the directions of traverses B and C. Accordingly, the soils along traverse A are moderately higher in lead content than those along traverses B and C, and the lead content displays better correlation with distance from the stack.

Most of the soil samples collected along traverses A, B, and C at a depth of 6 to 10 inches contain lead in amounts greater than generally found in similar soils outside the Helena Valley, but the amounts are much lower than those found in the upper 4 inches of soil. Nearly all of the samples taken in the 6- to 10-inch depth zone were taken below the existing plow layer. Some lead may have been introduced into this zone by physical mixing caused by deeper plowing in previous seasons, but most of it has probably moved downward by chemical leaching processes. The general chemical immobility of lead in soils is reflected by the fact that the upper 4-inch layer in the vicinity of the smelter tends to contain about 10 times more lead than the soil at a depth of 6 to 10 inches.

The upper 1 inch of soil at four sampling localities along the irrigation ditch (traverse D), where the soils have probably not been cultivated for 20 years or more, tends to contain more lead than cultivated surface soils along traverses A, B, and C. This is due to the absence of homogenization that occurs with plowing. The lead present at depth in the uncultivated soils probably results largely from chemical leaching of lead at the surface and redeposition below.

Samples collected near the highway 2 miles west of East Helena (sampling site H1, Figure 4-1) contain about the same amounts of lead as other surface samples from areas the same distance from the smelter stack. Samples collected near the tracks of the Northern Pacific Railroad (sampling site H2), however, contain up to almost 5000 ppm lead. The lead here has probably been derived from railroad cars transporting ore and ore concentrates to and from the smelter, or from the fill materials that form the railroad bed.

Zinc

The geometric mean zinc content of soils of the United States is given by Shacklette, Hamilton, Boerngen, and Bowles[7] as 44 ppm, with a geometric deviation of 1.86. Approximately 95 percent of the soils of the United States, therefore, have zinc contents in the range of 13 ($44/1.86^2$) to 152 (44×1.86^2) ppm. Soil samples collected in this investigation from the upper 4-inch soil layer in areas outside the Helena Valley have a geometric mean zinc content of 58 ppm; the geometric mean zinc content of those from a depth of 6 to 10 inches is only slightly less, 50 ppm. Soils in the vicinity of the Helena Valley, but of the same general type as those found around East Helena, therefore do not contain unusually high amounts of zinc.

The highest amounts of zinc in the soils of the Helena Valley were found within a mile of the smelter stack and along the tracks of the Northern Pacific Railroad. Nearly all soil samples collected from the upper 4-inch layer within a mile of the smelter stack contained 200 ppm or more zinc—more than 4 times as much zinc as that in similar soils outside the Helena Valley. Extraordinarily high zinc contents of soils (up to 5000 ppm) along the tracks of the Northern Pacific Railroad 2 miles west of East Helena are too high to have resulted from smelter stack emissions; the zinc is thought to have been derived either from railroad cars transporting ores and ore concentrates to and from the smelter, or from fill materials of which the track bed is formed.

The zinc content of the upper 4-inch soil layer tends to decrease systematically away from the smelter stack along traverses A, B, and C for a distance of 10 to 15 miles. The rate of decrease is less than that for lead because the zinc contents of soils near the smelter stack tend to be only about 4 times higher than normal.

The zinc contents of soils collected at a depth of 6 to 10 inches along traverses A, B, and C within a radius of several miles from the smelter stack tend to be about one-half those of samples collected from the upper 4-inch soil layer in the same area. This contrasts with the lead contents of the soils at depth, which tend to be about one-tenth of those of the soils at the surface, and reflects the greater chemical mobility of zinc in soil profiles. Canney,[10] for example, found in a study of soil contamination near a smelter in Idaho that the zinc contents of soils were similar in depth intervals of 0 to 2 inches and 2 to 6 inches, whereas the lead contents of soils from the lesser depth zone were considerably higher. The mobility of zinc in soils has been widely recognized in geochemical exploration.[11]

The greater chemical mobility of zinc is also indicated in the uncultivated soil samples collected along the irrigation ditch north of East Helena (traverse D). There the zinc in samples collected at a depth of 2 to 4 inches tends to be nearly the same as that in samples from the upper 1-inch layer.

Cadmium

Hawkes and Webb[11] give the average cadmium content of soils as 0.5 ppm, which is close to the geometric mean cadmium content of the soils collected outside the Helena Valley in this investigation. This mean is estimated to be approximately 0.8 ppm, and the range is from less than 0.5 to 2 ppm.

The highest cadmium content was found in soils collected near the smelter stack; approximately 150 ppm cadmium was found in samples collected from the upper 4-inch soil layer 0.67 mile northwest of the stack along traverse C. The cadmium content of the upper 4-inch soil layer, like the lead and zinc content, decreases systematically with distance from the stack, but no soils taken beyond a distance of about 5 miles from the stack were found to contain more cadmium than those soils sampled outside the Helena Valley. This does not necessarily mean that cadmium contained in smelter stack emissions is less widely dispersed than lead or zinc; cadmium is more difficult to assess because it is less abundant.

The cadmium content of soils collected at a depth of 6 to 10 inches is one-fifth to one-tenth of that in soils of the upper 4-inch layer, indicating that the chemical mobility of cadmium in the soils is somewhat greater than that of lead, but less than that of zinc. This is in accord with the observed general behavior of cadmium in soils as reported from studies in geochemical prospecting.[11]

The upper 1 inch of uncultivated soil along the irrigation ditch north of East Helena (traverse D) tends to contain more cadmium, in addition to lead and zinc, than the cultivated soils along traverses A, B, and C.

The cadmium content of soils collected near the highway 2 miles west of East Helena is no higher than that of other samples collected the same distance from the smelter, but the samples collected near the tracks of the Northern Pacific Railroad contain as much as 41 ppm cadmium.

Arsenic

The arsenic content of soils generally ranges from 1 to 50 ppm and averages about 5 ppm.[11] Samples collected in this investigation from the upper 4-inch soil layer outside the Helena Valley have a geometric mean arsenic content of 6 ppm. The geometric mean for samples from a depth of 6 to 10 inches is only about 1 ppm.

Soil samples collected from the upper 4-inch layer within a mile of the smelter stack contain up to 150 ppm arsenic, and commonly contain more than 50 ppm. The arsenic content decreases systematically away from the stack for a distance of 5 to 10 miles along traverses A and B, although the distribution of arsenic in the soils along traverse C appears to be erratic.

The arsenic content of soil samples collected at a depth of 6 to 10 inches indicates that the chemical mobility of arsenic in the soil, like that of cadmium, is intermediate between the mobilities of lead and zinc. The soils at this depth near the smelter tend to contain one-fourth to one-half as much arsenic as soils in the upper 4-inch layer.

Samples from the upper 1 inch of soil collected near the highway west of East Helena do not contain more arsenic than should be expected, considering the distance of the sampling site from the smelter stack; those samples taken near the railroad tracks, however, contain high amounts of arsenic in addition to lead, zinc, and cadmium.

Other Elements

Spectrographic analyses for 25 additional elements were made on samples selected at random from the total group of samples collected in this investigation. Among the elements that appear to be highly concentrated in soils from near the smelter, in addition to lead and zinc, are iron, silver, barium, cobalt, chromium, copper, manganese, and vanadium. Further study would be required to verifiy this, however.

SUMMARY AND CONCLUSIONS

The soils of the Helena Valley are developed on fill materials derived from the surrounding mountain ranges, and on lake sediment of Tertiary age. None of the rock types that form the ranges are known to contain amounts of lead, zinc, cadmium, and arsenic comparable to the amounts found in the Helena Valley soils. The principal rock out-crops in or near the floor of the Valley are of siltstone of the Belt Series of Precambrian age and of the lake sediments. The lake sediments, rich in tuffaceous materials of volcanic origin, show no detectable lead or arsenic, and only low to moderate amounts of zinc and cadmium. Similarly, siltstones of the Belt Series were not found to contain any appreciable quantities of any of these metals. Soils in the vicinity of, but outside, the Helena Valley – and of the same type as present in the Helena Valley – were found to contain no more lead, zinc, cadmium, and arsenic than is characteristic of soils elsewhere.

Within a radius of at least 10 miles from the smelter at East Helena, the soils contain abundantly more lead, zinc, cadmium, and arsenic than similar types of soils in the vicinity of, but outside, the Helena Valley. They also contain far more of these metals than do soils of the United States in general. Lead occurs in concentrations of up to 6800 ppm (0.68 percent), zinc in concentrations up to 5200 ppm (0.52 percent), cadmium in concentrations up to 160 ppm (0.016 percent), and arsenic in concentrations up to 150 ppm (0.015 percent). The highest concentrations of these metals found in similar kinds of soil outside the Helena Valley were 50 ppm lead, 75 ppm zinc, 2 ppm cadmium, and 20 ppm arsenic.

The lead, zinc, cadmium, and arsenic contents of the soils decrease systematically away from the smelter stack. The decrease is found to be linear on log-log scales; the logarithm of the metal content decreases linearly with the logarithm of the distance from the stack. This relationship is particularly well defined in the upper 4-inch soil layer. For example, the lead content of a soil sample from a depth of 0 to 4 inches, taken at a given distance ESE of the smelter stack, can be predicted within a factor of 1.37, with a confidence of 95 percent. The zinc content of the same sample can be predicted within a factor of 1.44, cadmium within a factor of 1.22, and arsenic within a factor of 2.58, all at the 95 percent level of confidence.

The extent of the area contaminated by emissions from the smelter stack is best defined by the distribution of lead in the upper 4-inch soil layer. The contamination extends in an east-southeast direction to the southern end of the Spokane Hills, a distance of about 10 miles. Soils located just east of the pass at the southeast end of the Valley, however, do not appear to have been contaminated. Lead contamination of the soils extends for at least 5 miles north-northeast from the smelter, and for 10 to 15 miles to the northwest.

Nearly all of the soils sampled in this investigation were collected in pairs, one sample from the upper 4 inches and another at a depth of 6 to 10 inches. The upper 4 inches of soil was cultivated at almost all of the sampling localities; the soils at a depth of 6 to 10 inches were generally below the existing plow layer. Uncultivated soils were sampled at three depth zones along an irrigation ditch north of East Helena. The data indicate that lead, zinc, cadmium, and arsenic have migrated downward for at least 6 to 10 inches in both cultivated soils and in soils that have not been under cultivation for 20 years or more. Comparison of the amounts of metals present in the surface soils with those at depth indicates that zinc is the most mobile of the four elements studied. This finding is in accord with previous observations of the chemical behavior of these metals in soil environments. Lead, zinc, cadmium, and arsenic are present at a depth of 6 to 10 inches in amounts ranging from 10 to 50 percent of the amounts present in the upper 4-inch soil layer.

Soils along the highway 2 miles west of East Helena contain no more lead, zinc, cadmium, or arsenic than other soils the same distance from the smelter. Highway contamination – contamination caused by automobile exhaust, in particular – appears to have been masked by contamination from the smelter operation. Lead contamination of soils and vegetation along highways has been found to be significant in other areas.[12]

Soils along the tracks of the Northern Pacific Railroad 2 miles west of East Helena are contaminated with lead and zinc, and with cadmium and arsenic to a lesser extent, beyond that which can reasonably be attributed directly to the smelter. The contamination extends for a distance of 80 feet or more from the tracks and probably results largely from railroad cars carrying ores and ore concentrates to and from the smelter.

The arithmetic mean concentrations of lead, zinc, cadmium, and arsenic in the upper 4-inch soil layer within a radius of 0.67 to 10 miles from the smelter stack at East Helena, estimated by integration of the appropriate regression equations, are as follows:

1. Lead – 69 ppm.
2. Zinc – 79 ppm.
3. Cadmium – 2.5 ppm.
4. Arsenic – 11 ppm.

Similar estimates for the 6- to 10-inch depth zone are:

1. Lead – 22 ppm.
2. Zinc – 58 ppm.
3. Cadmium – 1 ppm.
4. Arsenic – 7 ppm.

Assuming that the original metal contents of the soils were similar to the mean concentrations of the metals in the soil samples collected outside the Helena Valley in this investigation, the amounts of each that have been added by smelter contamination to the upper 10 inches of soil in the area beyond 0.67 mile from the smelter are as follows:

1. Lead – 10,000 tons.
2. Zinc – 5,600 tons.
3. Cadmium – 290 tons.
4. Arsenic – 860 tons.

REFERENCES FOR CHAPTER 4

1. Mertie, J. B., Jr., R. P. Fischer, and S. W. Hobbs. Geology of the Canyon Ferry Quadrangle, Montana. U.S. Geol. Survey Bull. 972. p. 97. 1951.
2. Pardee, J. T. and F. C. Schrader. Metalliferous Deposits of the Greater Helena Mining Region, Montana. U.S. Geol. Survey Bull. 842. p.318. 1933.
3. Huffman, Claude, Jr., and J. A. Thomas. Unpublished atomic absorption technique. U.S. Geological Survey, Denver, Colorado.
4. Nakagawa, H. M. and T. F. Harms. Atomic Absorption Determination of Cadmium in Geologic Materials. U.S. Geol. Survey Prof. Paper 600-D. p. D207-D209. 1968.
5. Huffman, Claude, Jr. Copper, Strontium, and Zinc Content of U.S. Geological Survey Silicate Rock Standards. U.S. Geol. Survey Prof. Paper 600-B. p. B110-B111. 1968.
6. Ward, F. N. et al. Analytical Methods Used in Geochemical Exploration by the U.S. Geological Survey. U.S. Geol. Bull. 1152. p.100. 1963.
7. Shacklettee, H. T., J. C. Hamilton, J. G. Boerngen, and J. M. Bowles. Elemental Composition of Surficial Materials in the Conterminous U.S. U.S. Geol. Survey Prof. Paper 574-D. (In press.)
8. Cohen, A. C., Jr. Tables for Maximum Likelihood Estimates; Singly Truncated and Singly Censored Samples. Technometrics, *3*(4):535-541. 1961.
9. Miesch, A. T. Methods of Computation of Estimating Geochemical Abundance. U.S. Geol. Survey Prof. Paper 574-B. p.15. 1967.
10. Canney, F. C. Geochemical Study of Soil Contamination in the Coeur D'Alene District, Shoshone County, Idaho. Mining Engineering, *11*(2):205-210. 1959.
11. Hawkes, H. E. and J. S. Webb. Geochemistry in Mineral Exploration. Harper and Row, Inc., New York. p.415. 1962.
12. Cannon, H. G. and J. M. Bowles. Contamination of Vegetation by Tetraethyl Lead. Science, *137*(3532): 765-766. 1962.

5. SOIL AND VEGETATION STUDY

Ibrahim J. Hindawi, Ph.D., and Grady E. Neely

ENVIRONMENTAL PROTECTION AGENCY
National Environmental Research Center

INTRODUCTION

During the summer of 1969, a study was undertaken in the Helena Valley area of Montana to determine the effects pollutants were having on area vegetation. The pollutants of interest were arsenic, cadmium, lead, zinc, and sulfur dioxide.

The investigation had three purposes: (1) to determine how vegetation is being contaminated by heavy metals, (2) to determine the concentrations of heavy metals being accumulated in vegetation in the area, and (3) to assess any sulfur dioxide damage that might be occurring in the Valley.

ORIGIN OF HEAVY METALS IN VEGETATION

Methods and Materials

To determine how suspected pollutants were affecting vegetation in the Helena Valley area, certain plants – indigenous to the area – were grown under controlled conditions at four locations in the study area from June 27 through September 4, 1969, a period of 10 weeks. The two suspected media of transfer were air and soil. A small, cylindrically shaped, glass-fiber greenhouse, 6 by 6.5 feet (Figure 5-1), was located at each of the four sites. In relation to the stack of the American Smelting and Refining Company (ASARCO), station 1 was 0.8 mile northeast; station 2 was 2.5 miles east; station 3 was 0.4 mile southeast; and station 4 was 4.5 miles west, as indicated in Figure 5.2. Fans in the greenhouses were designed to circulate air through at one change per minute. Two additional greenhouses were placed at station 1. These were equipped with particulate and activated-charcoal filters for the purpose of purifying the air inside the shelters.

Four of the plants studied – alfalfa, pinto bean, carrot, and beet – were selected because they are commonly grown and are consumed by both man and animals in the study area. Two others – petunia and tobacco – were included because of their sensitivity to SO_2.

All plants in the ambient-air greenhouses and those in one of the purified-air shelters were grown hydroponically in a vermiculite support medium. Plants in 8-inch plastic pots were placed in shallow plastic trays to which a distilled-water

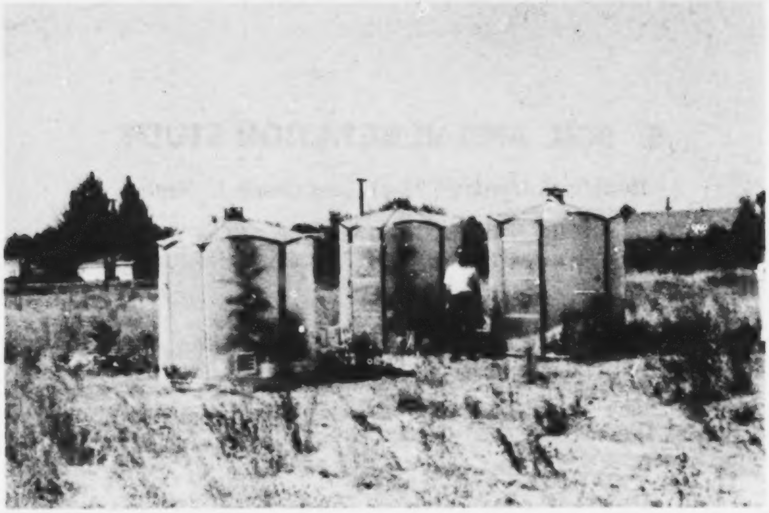


Figure 5-1. Control and exposed plant sites at station 1.

nutrient solution was added twice a week. The potted plants were flushed weekly with distilled water, and the trays were cleaned weekly to rid them of algae.

In the remaining greenhouse supplied with purified air, plants were grown in plastic pots containing one of two soils. One soil (East Helena) was expected to exhibit a high range of heavy-metals concentration, and the other (East Helena composite) was thought to possess a medium range of concentration relative to the metal content of the soil in the immediate East Helena area. The former was taken from 0.6 mile southeast of the town; the latter was composed of equal amounts of soil from four locations between 0.5 and 1 mile of East Helena on the north, east, south, and west sides of town. The soil composite from the four locations was mixed thoroughly before being placed in the pots. All plants grown in soil-containing pots were watered with distilled water and nutrient solution approximately three times a week. Identical plants were planted in a small garden at each of the four locations. These plants were watered with distilled water and nutrient solution approximately two times a week.

At the end of the 10-week period, unwashed plant samples were sent to the U.S. Food and Drug Laboratory at Denver, Colorado, for analyses. Cadmium, lead, and zinc analyses were performed by means of atomic absorption spectrophotometry. Arsenic was analyzed by the silver diethyldithiocarbamate method. All plant-sample concentrations were expressed in parts per million (ppm) on a wet-weight basis. Soil samples that corresponded to the vegetation samples were sent to the U.S. Geological Survey in Denver for analyses. Soil-sample concentrations were expressed in ppm on a dry-weight basis.

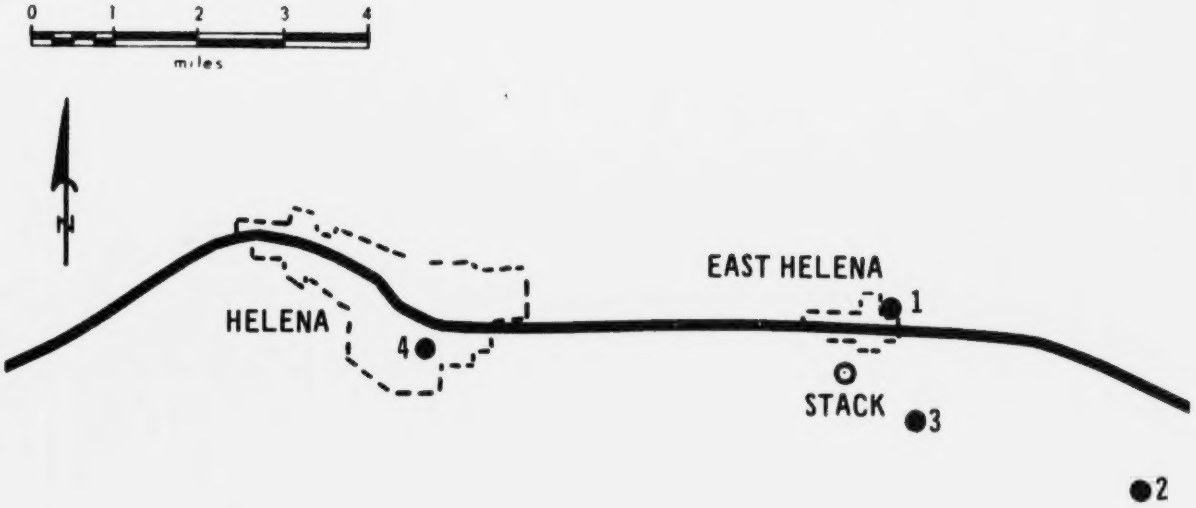

0
1
2
3
4
miles
N
HELENA
4
EAST HELENA
1
STACK
3
2

Figure 5-2. Locations of greenhouses and experimental gardens in the East Helena study.

Results and Discussion

Table 5-1 presents the metal contents of samples of vermiculite and soils used to grow the vegetation during the study. The metal content of vermiculite did not change with use and was lower than the metal content of any of the soils used during the study. The soil with the highest metal content came from station 3, and the one with the lowest came from station 4.

Table 5-1. HEAVY-METAL CONTENT OF VERMICULITE AND SOILS USED IN GREENHOUSES AND EXPERIMENTAL GARDENS

(ppm)

Material	Arsenic	Cadmium	Lead	Zinc
Unused vermiculite	<5	1.5	30	75
Used vermiculite	<5	1.5	30	75
E. Helena soil	35	19.0	615	200
E. Helena soil composite	35	16.5	490	232
Soil at station 1	35	21.0	925	455
Soil at station 2	25	6.5	190	126
Soil at station 3	50	56.0	1,525	418
Soil at station 4	8	2.0	85	83

Table 5-2 gives the metal contents for the vegetation samples. A composite of all the plants grown was taken to form a single sample for each growing procedure. A comparison of the analyses of hydroponically grown vegetation with the analyses of that grown in ambient air reveals that neither metals in fine-particle form nor those in the gaseous state were a major source of the heavy metals that accumulated in the vegetation. Although the vegetation from station 3 had significantly higher metal contents, this was probably caused by particulate matter adhering to the plant surfaces. At this station near the end of the study period, a sudden wind storm deposited surface soil on the plant leaves while the pots and trays were being cleaned outside the greenhouse. At the close of the study, this same particulate matter was still on the leaves – especially the sticky and pubescent surfaces of tobacco and petunia.

Plants grown in soil inside the filtered-air greenhouse had higher concentrations of metals than did the plants grown in vermiculite. A comparison of both analyses confirms that plants are capable of accumulating arsenic, cadmium, and zinc through their root systems. Because there was no significant difference in lead concentrations, however, it may be possible that lead is not assimilated through the root system.

Table 5-2. AVERAGE HEAVY-METAL CONTENT OF EXPERIMENTAL VEGETATION [a]

(ppm)

Where grown	Arsenic	Cadmium	Lead	Zinc
Greenhouse in vermiculite				
Station 1 – Control filtered air	0.1	0.1	3.5	6.8
Station 1 – Exposed to ambient air	0.4	0.3	2.6	8.2
Station 2 – Exposed to ambient air	>0.0	0.1	1.5	5.6
Station 3 – Exposed to ambient air	1.7	0.9	7.4	14.0
Station 4 – Exposed to ambient air	>0.0	0.2	0.6	3.0
Greenhouse in soil				
Station 1 – E. Helena soil in filtered air	1.7	5.2	5.1	67.8
Station 1 – E. Helena composite soil in filtered air	1.6	3.0	2.9	14.0
Experimental gardens in soil				
Station 1	2.5[b,c]	8.6[b,c]	5.4[b,c]	60.5[b,c]
Station 2	1.0	1.3	3.0	13.1
Station 3	8.4[d]	7.5[d]	48.3[d]	52.2[d]
Station 4	0.4[c]	0.7[c]	1.0[c]	11.5[c]

[a] Samples were not washed prior to analyses.

[b] Alfalfa not included here because of lost sample.

[c] Lettuce is included in the average.

[d] Pinto bean is not included in the average.

Figures 5-3 and 5-4 reveal that the concentrations of metals in or on the plants varied directly with the concentrations found in the soils in which the plants were grown. This was true for lead as well as arsenic, cadmium, and zinc. Because none of the samples were washed prior to analysis, it can not be concluded that the metals found had accumulated in the plant tissue. Some of the metal content could have come from windblown or rain-splattered surface soil or from large particles settling from the air on the plant surfaces.

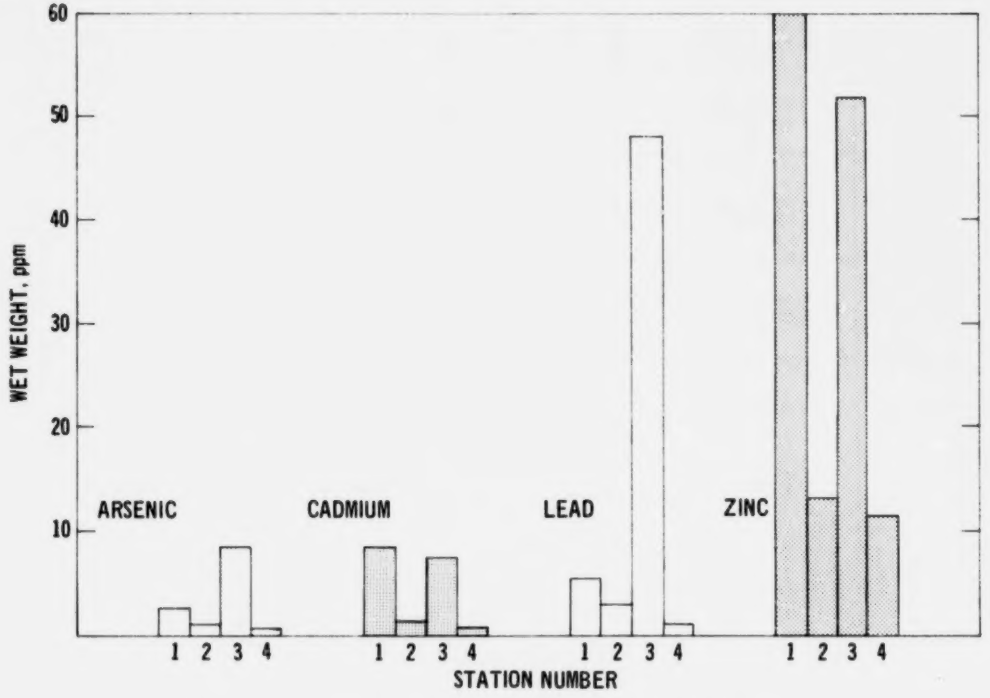


Figure 5-3. Average heavy-metal levels in plants grown in experimental gardens around East Helena in 1969.

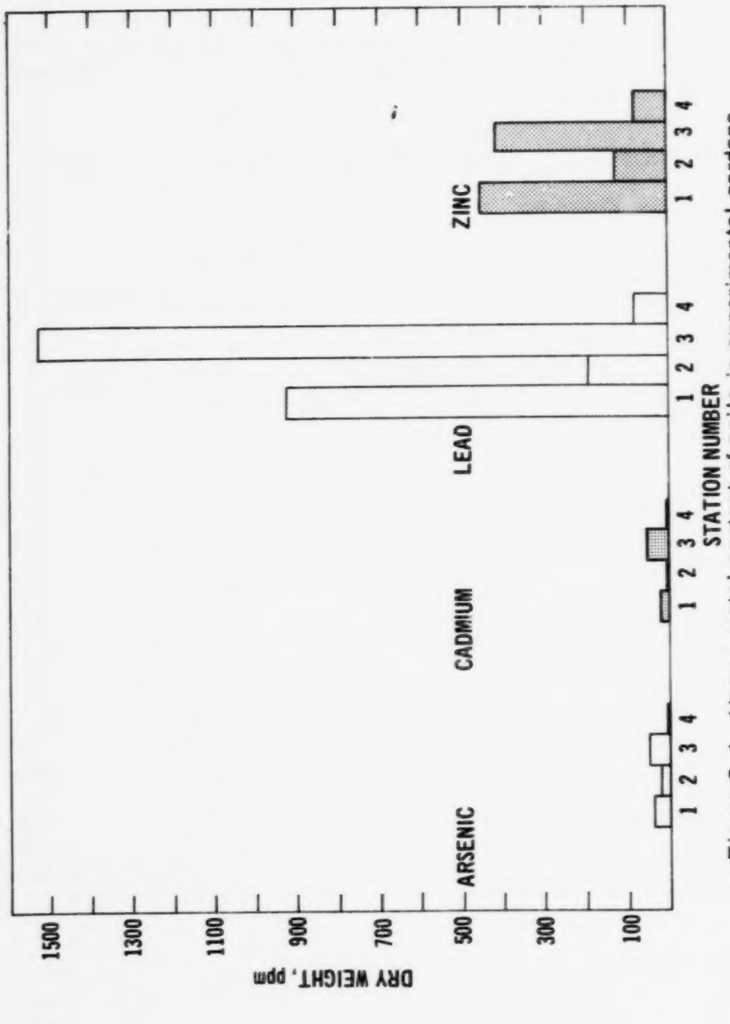


Figure 5-4. Heavy-metal content of soils in experimental gardens around East Helena in 1969.

SUMMARY

Arsenic, cadmium, lead, and zinc in the forms of gases or fine particles are not a major source of vegetable contamination in the Helena Valley.

Arsenic, cadmium, and zinc can be assimilated into the plant tissues through the plant root system.

The arsenic, cadmium, lead, and zinc concentrations found in the experimentally grown vegetation in the study area varied directly with the metal concentrations found in the soil.

AMOUNT OF HEAVY METALS IN SOILS AND VEGETATION

Methods and Materials

Random samples of edible portions of garden vegetables and crops were taken from within 4 miles of East Helena during August and September of 1969. Surface-soil samples, from a depth of 6 inches, were also taken from these same locations.

Both the plant and soil samples were sent to Denver, Colorado, for analyses–the former by the U.S. Food and Drug Administration, and the latte by the U.S. Geological Survey.

Results and Discussion of Soil Analyses

The analyses for arsenic, cadmium, lead, and zinc contents of the soils generally indicated that the concentrations of these metals varied inversely with the distance from the smelter. Soil samples were consistent in that if a sample contained a high concentration of one metal, then the other metals were also present in high concentrations. This characteristic was true for medium and low values as well.

Grasslands in the Helena area are tilled very infrequently, and the alfalfa fields are tilled about once every 5 years. The gardens and wheat, barley, and oat fields are plowed yearly, however. A comparison of the analyses of soil samples indicates that the concentrations of metals were highest in the soils of grass and alfalfa; concentrations found in the soils of the gardens and wheat, barley, and oat fields were somewhat lower. This finding indicates that the metal concentrations are building up in the soil from the surface down. The more often soils are tilled, the more thoroughly the plow layer is mixed and the faster that leaching of metals takes place.

The 69 soils sampled within 4.5 miles of the smelter had metal contents ranging from 5 to 160 ppm for arsenic, 2 to 42 ppm for cadmium, 65 to 1530 ppm for lead, and 70 to 9400 ppm for zinc. The ranges of these values are much greater than normally would have been expected in soil samples from such a small area.

Results and Discussion of Vegetation Analyses

Concentrations of arsenic, cadmium, lead, and zinc in wheat kernels, barley kernels, oat kernels, pasture grass, alfalfa, and lettuce in the East Helena area did not indicate an inverse relationship with distance from the smelter. As was true with soil analyses, however, vegetation samples in the same area indicated pasture grasses contained greater metal concentrations than alfalfa, and alfalfa contained higher levels than wheat, barley, oats, and most garden vegetables.

For each metal, the overall concentration range, on a wet-weight basis, was: arsenic, 0 to 12 ppm; cadmium, a trace to 9.8 ppm; lead, a trace to 100 ppm; and zinc, 0.5 to 232 ppm.

The ranges of heavy metals found in plant species sampled from residential gardens and ranches within 4 miles of East Helena are presented in Table 5-3.

Table 5-3. RANGES OF HEAVY METALS IN PLANTS SAMPLED FROM RESIDENTAIL GARDENS AND RANCHES IN EAST HELENA AREA

Plant type	No. of samples	Metal range, ppm[a]			
		Arsenic	Cadmium	Lead	Zinc
Garden					
Apple	2	T[b] – 0.1	T – 0.1	0.7 – 0.8	0.5 – 1.9
Beet	9	0.0 – 0.4	0.1 – 2.5	0.4 – 15.0	4.1 – 67.1
Cabbage	5	0.0 – 0.9	T – 0.4	T – 8.6	2.2 – 15.1
Carrot	11	0.0 – 2.9	0.1 – 0.4	0.3 – 4.0	3.1 – 35.5
Kohlrabi	2	T – 0.1	0.1 – 0.2	0.1 – 4.1	3.5 – 8.9
Lettuce	10	0.0 – 2.1	0.2 – 3.4	1.2 – 17.2	6.1 – 36.1
Onion	5	T – 3.2	0.1 – 0.5	0.4 – 1.8	6.2 – 17.4
Potato	10	0.0 – 0.1	T[c] – 0.2	0.1 – 1.3	3.0 – 8.4
Radish	1	T	0.6	3.4	12.0
Rutabaga	1	0.5	0.3	3.1	7.0
String bean	2	T	0.1[d]	0.1 – 0.2	4.4 – 7.1
Sunflower leaf	1	3.3	1.0	15.4	27.0
Sweet pea	4	T – 0.1	T – 0.2	0.4 – 1.5	7.4 – 21.9
Field					
Alfalfa	16	0.4 – 5.7	0.3 – 3.2	2.5 – 42.0	24.0 – 124.0
Barley kernel	8	0.0 – 0.9	0.1 – 1.2	0.3 – 9.8	23.0 – 73.0
Barley straw	1	14.3	6.3	142.8	105.9
Oat kernel	1	0.1	0.6	1.1	32.2
Pasture grass	11	2.5 – 12.0	1.2 – 9.8	1.4 – 100.0	56.0 – 232.0
Wheat kernel	24	T – 0.0	0.1 – 1.5	0.1 – 1.5	33.0 – 86.0

[a] On a wet-weight basis.

[b] Trace ≤ 0.05 ppm.

[c] Only nine samples.

[d] Only one sample.

These ranges varied greatly from species to species. A grouping of vegetation by type in Table 5-4 showed definite rankings. From highest to lowest concentration, the ranking was pasture grasses, alfalfa, garden plants, and small grains. The highest metal levels found in the grasses ranged from 3 to 10 times higher than the highest levels found in small grains.

Table 5-4. RANGES OF HEAVY METALS IN GARDEN PLANTS, SMALL GRAINS, ALFALFA, AND PASTURE GRASSES SAMPLED IN EAST HELENA AREA IN 1969

Plant type	Metal range, ppm[a]			
	Arsenic	Cadmium	Lead	Zinc
Garden	0 – 3.3	T[b] – 3.4	T – 17.2	0.5 – 67.1
Small grain	0 – 0.9	0.1 – 1.2	0.1 – 9.8	23.0 – 73.0
Alfalfa	0.4 – 5.7	0.3 – 3.2	2.5 – 42.0	24.0 – 124.0
Pasture grass	2.5 – 12.0	1.2 – 9.8	1.4 – 100.0	56.0 – 232.0

[a] On a wet-weight basis.

[b] T $\leq$ 0.05 ppm.

SUMMARY

Generally, soil concentrations of each metal studied varied inversely with distance from the stack. Soils that had high concentrations of one metal usually had high concentrations of the other metals studied. This similarity also held true for lesser concentrations. Soil metal concentrations varied inversely with frequency of soil tillage; this indicated a metal buildup from the surface downward. The concentration ranges for arsenic, cadmium, lead, and zinc in soils varied more than normally would have been expected in such a small area.

Concentrations of arsenic, cadmium, lead, and zinc in vegetation from the study area varied more than would have been expected in an area of similar size. Factors affecting the amount of metals found in vegetation in the study area were soil metal levels, plant species, and portions of plant sampled.

VISIBLE PLANT DAMAGE TO INDIGENOUS AND GREENHOUSE VEGETATION

Methods and Materials

Information concerning the visible effects of sulfur dioxide on both indigenous and experimentally grown vegetation was gathered in the study area during the 1969 growing season. Inspection tours were made by the staff of the Vegetation Effects Section to find the incidence of sulfur dioxide damage to indigenous vegetation. These inspections consisted of observing vegetation at several locations throughout the study area.

An assessment of possible visible injury by air pollutants to experimentally grown vegetation was made at the end of the study. The methods and materials used to grow the experimental vegetation were listed earlier in this chapter. Only vegetation grown in vermiculite in greenhouses was assessed for damage. Comparisons of growth suppression and dwarfing were not made among plants grown in vermiculite.

Results and Discussion

The findings made from the indigenous vegetation inspection tours in the study area are reported in Table 5-5. Sulfur dioxide plus acid-mist injury

Table 5-5. INJURY FOUND ON INDIGENOUS VEGETATION

Date	Plant	Location	Type injury	Degree of damage[a]
6/20/69	Alfalfa	Tom Dartmen residence, 1800 yards north of ASARCO	SO_2	M
7/22/69	Hedges,	Park in East Helena, 1000 yards north of ASARCO	SO_2 + acid mist	E
	English hawthorne,		SO_2 + acid mist	M
	sun flower,		SO_2 + acid mist	M
	mock orange,		SO_2 + acid mist	T
	blueberry		SO_2 + acid mist	M
7/22/69	Columbine	A.J. Vollmer residence, 800 yards east of ASARCO	SO_2	E
7/22/69	Lilac	Paul Kleffner residence, 1800 yards southeast of ASARCO	SO_2	T
	sweet pea,		SO_2	E
	apple,		SO_2	M
	tomato,		SO_2	M
	lettuce		SO_2	T
7/22/69	Grape,	Gregory Schaff residence, 1200 yards northeast of ASARCO	SO_2	E
	rhubarb,		SO_2	T
	plum,		SO_2	M
	corn,		SO_2	T
	sweet potato		SO_2	E
7/22/69	Alfalfa	George Marcinkowski residence, 1200 yards south of ASARCO	SO_2 + acid mist	M
	apple,		SO_2	M
	mustard		SO_2 + acid mist	T
8/26/69	Pansy,	Vollmer residence	SO_2	T
	petunia,		SO_2	M
	sweet pea,		SO_2	E
	dahlia,		SO_2	M
	columbine		SO_2	M

[a] T (trace) = 0 to 5 percent of leaf area damaged; M (moderate) = 5 to 25 percent of leaf area damaged; E (extensive) = 25 to 50 percent of leaf area damaged.

developed on several plant varieties at two locations. Sulfur dioxide alone was the cause of leaf injury at the other locations. All locations where injury was found were within 1 mile of the stack of American Smelting and Refining Company.

Table 5-6 summarizes the leaf damage found on the experimental vegetation at three sites. In this table, both type and amount of damage are listed. When the type of injury is specific to a certain pollutant, it is listed according to pollutant; however, if the type is nonspecific, it is listed according to type of damage, such as chlorosis. An example of the sulfur dioxide injury found on alfalfa leaves at station 3 is shown in Figure 5-5.

Table 5-6. TYPE AND EXTENT OF LEAF DAMAGE ON EXPERIMENTAL VEGETATION

Damage type/Plant species	Degree of injury at three locations[a] 1	2	3
Sulfur dioxide			
Tobacco	T	T	
Pinto bean		T	
Petunia			M
Alfalfa		T	E
Beet		T	M
Carrot		M	M
Ozone			
Tobacco	T		
Synergistic (SO_2 + O_3)			
Tobacco			M
Pinto bean			M
Chlorosis			
Tobacco		M	T
Pinto bean	T	M	
Petunia	T	M	
Alfalfa	T	T	
Beet	T	T	
Carrot		T	

[a] T (trace) = 0 to 5 percent of leaf area damaged.
M (moderate) = 5 to 25 percent of leaf area damaged.
E (extensive) = 25 to 50 percent of leaf area damaged.

Relatively low concentrations of ozone and sulfur dioxide, when mixed, will cause damage to vegetation. Evidence of damage from mixture of these pollutants was observed on vegetation at stations 1 and 3. The combination of ozone and sulfur dioxide reduces the injury threshold of the leaf tissue and increases the damage beyond that from the individual pollutants.

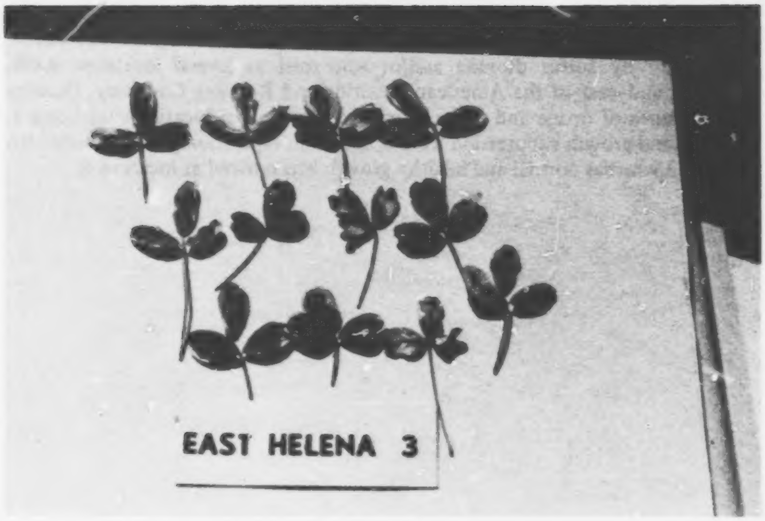


Figure 5-5. Sulfur dioxide leaf injury to alfalfa at station 3.

In addition to tissue destruction, the growth of experimental vegetation, except at station 4, was suppressed. Table 5-7 lists the percentage by which exposure specimens were smaller than the controls specimens of the same age.

A suppression value of 20 percent means that the plant growth in an exposure chamber was estimated by visual comparison to be 20 percent less than that of a similar plant grown in the control site.

Table 5-7. GROWTH SUPPRESSION OF EXPERIMENTAL VEGETATION
(% < control)

	Control	Exposed			
Plant	1	1	2	3	4
Tobacco	0	30	20	30	0
Pinto bean	0	10	15	15	0
Petunia	0	15	10	20	0
Alfalfa	0	10	10	20	0
Beet	0	10	10	15	0
Carrot	0	10	15	15	0

[a] Suppression of growth at stations 1 and 3 was noticed in experimental vegetation grown in soil.

SUMMARY

Study and observations of the indigenous and selective vegetation revealed plant injury by sulfur dioxide and/or acid mist in several locations north, northeast, and east of the American Smelting and Refining Company. Damage from mixtures of ozone and sulfur dioxide was noticed at location sites 1 and 3. Dwarfing and growth suppression were observed in vegetation grown at locations 1, 2, and 3, whereas normal and healthy growth was noticed at location 4.

6. EFFECTS OF AIR POLLUTION ON INDIGENOUS ANIMALS AND VEGETATION

C. C. Gordon, Ph.D.

UNIVERSITY OF MONTANA
Department of Botany

INTRODUCTION

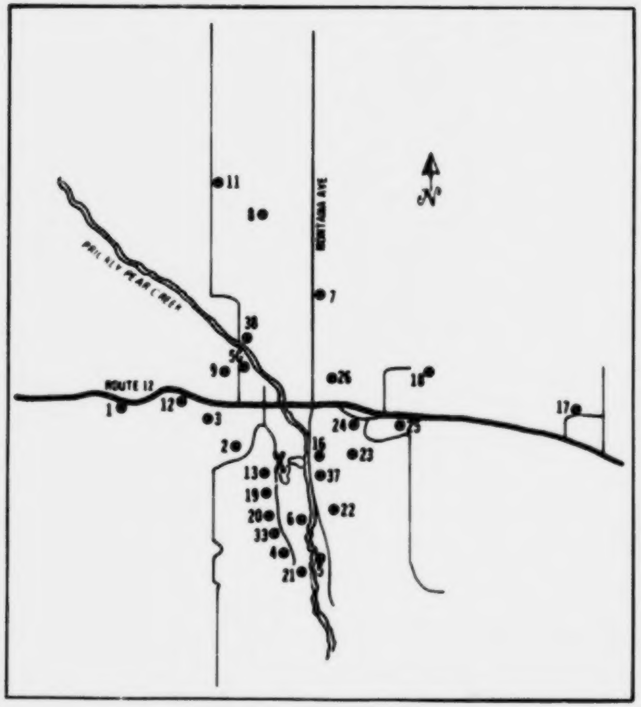
Investigations were undertaken (1) to document the association between concentrations of lead and cadmium in indigenous vegetation and in animals ingesting such vegetation, (2) to determine whether the accumulation of lead and cadmium in the vegetation surrounding the East Helena smelters results from absorption of the metals through the roots from the soil or through the leaf surfaces from the atmosphere, and (3) to assess the effects of sulfur dioxide on plants in the study area.

Five studies were initiated to accomplish the three objectives. The first study was to determine the extent of accumulation of lead and cadmium in indigenous animals and in the grasses upon which they feed. A second study was to quantitate the lead and cadmium content of garden vegetables growing in the area. The third study involved transfer of East Helena soil from several sites to Missoula, where vegetables (primarily lettuce) were grown and then assayed for lead and cadmium. A fourth study involved the feeding of rabbits with lettuce grown in several locations to determine the amount of accumulation of lead and cadmium in rabbit tissues as related to the food source. The fifth study was to examine indigenous conifer vegetation for damage produced by air pollution.

ACCUMULATION OF LEAD AND CADMIUM IN INDIGENOUS ANIMALS

During the months of July to November 1969, several species of rodents were captured in the vicinity of East Helena. These were: *Citellus columbianus* (Columbia ground squirrel), *Mus musculus* (house mouse), *P. leucopus* (white-footed deer mouse), *Eutamius amoenus* (yellow pine chipmunk), *Microtus pennsylvanicus* (meadow vole), *M. momtarius* (montane vole), *M. logicaudis* (long-tailed vole), *Lepus townsendii* (white-tailed jackrabbit), *Sylvilagus nuttallii* (mountain cottontail).

Approximately 135 animals were collected from 28 sites, some of which are shown in Figure 6-1. Small rodents were collected by live traps; the traps were



STATION	LOCATION
1	M.V. JOHNSON RESIDENCE
2	RACETRACK
3	EAST HELENA DUMP
4	MARCHE RESIDENCE
5	KLEFFNER RESIDENCE
6	SUMNER RESIDENCE
7	ARMAGAST RESIDENCE
8	ARLIENT RESIDENCE
9	LAMPING RESIDENCE
10	PRICKLY PEAR BRIDGE ON LAMPING LAND
11	0.4 MILE NORTH OF GRAVEL PIT BY ARLIENT S CROSSING
12	HALFWAY BETWEEN EAST HELENA AND OVERPASS
13	ACROSS ROAD FROM ASARCO NEAR DUMP
16	VOLMER RESIDENCE
17	DIEHL RESIDENCE
18	R.F. MILLER RESIDENCE
19	0.25 MILE SOUTH OF STACK ALONG ROAD
20	0.5 MILE SOUTH OF STACK ALONG ROAD
21	MARCHIE ABANDONED FARM
22	0.5 MILE NORTH OF SUMNER RESIDENCE ON RAILROAD TRACK
23	1000 YARDS EAST OF VOLMER RESIDENCE IN A CULVERT
24	600 YARDS SOUTHEAST OF ROOTBEER STAND
25	AT DUMP 1000 YARDS EAST OF SITE 24
26	ROCK PILE 1000 YARDS NORTHEAST OF JUNCTION OF HIGHWAY 12 AND MONTANA AVENUE
33	BUFF RESIDENCE
37	BESSLER RESIDENCE
39	J. FINN RESIDENCE
x	ASARCO STACK

Figure 6-1. Animal collection sites.

set out one day and collected the next. The eight rabbits were shot or captured by hand. The animals were frozen immediately if dissection was not possible that day. In the laboratory liver and kidneys (and, in some cases, bones) were removed and frozen separately in plastic bags. The livers and kidneys of mice from one or several adjacent sites were combined in a composite in order to give enough tissue for assay. Rabbits and ground squirrels were reported independently because their feeding habits and accumulation patterns were considered to be radically different from those of mice. Six rabbits and one pig were included in the 1969 study. Control animals were taken from two areas, one at MacDonalds Pass (17 miles west of the study area) and the other at Potomac Valley (100 miles WNW of Helena).

Lead and cadmium analyses were done by the Wisconsin Alumni Research Foundation (WARF) Institute, Inc., of Madison, Wisconsin. The method used was atomic absorption spectrophotometry. The results of the analyses are shown in Table 6-1.

Table 6-1. LEAD AND CADMIUM IN ANIMAL TISSUES[a]
(ppm)

Site	Number of animals	Specimen	Lead			Cadmium	
			Bone	Liver	Kidney	Liver	Kidney
2,3	9	Mice		10.0	58.0	1.7	7.7
4,6	6	Mice		14.0	62.0	0.5	1.8
5,22	8	Mice		3.2	8.0	0.5	2.1
7,8,26	5	Mice		4.7	26.0	2.2	6.0
9,1	8	Mice		15.0	110.0	0.4	2.0
16	9	Mice		23.0	48.0	2.4	3.8
23,24,25	11	Mice		4.7	53.0	2.7	7.2
21	9	Mice		4.7	88.0	0.8	1.8
27	8	Mice		1.2	2.4	0.2	1.5
28,38	7	Mice		0.5	0.5	0.2	2.4
19,20	11	Mice		2.2	12.0	4.7	14.0
Potomac Valley	12	Mice		2.0	0.5	0.2	0.6
MacDonald Pass	4	Columbia ground squirrels		4.1	0.7	0.2	1.4
1,3,10, 11,12	5	Columbia ground squirrels		0.8	2.0	1.4	4.0
6	1	Rabbit		2.6	3.4	5.8	61.0
6	1	Rabbit		3.9	3.1	5.8	34.0
21	1	Rabbit		3.6	2.3	9.1	53.0
6	1	Rabbit		5.1	3.9	3.9	29.0
6	1	Rabbit		7.7	19.0	4.9	19.0
Missoula	1	Rabbit		<0.5	<0.5	0.1	0.3
6	1	Pig	73	2.6	2.7	0.2	0.8

[a] Fresh weight.

Because rodents are dependent upon the vegetation growing in the area, they are good indicators of the transfer of pollutants from the air into the natural food chain. In Table 6-2 are descriptions of the rodents trapped and pertinent information such as territorial range and eating habits. The effect on such wildlife populations as these rodents is more severe and more readily evident than on humans or domestic animals whose diet is only partly derived from locally grown foods. Beginning at conception, an indigenous animal is subjected to total-environment exposure.

Several trends emerged from the rodent data. One, expected from statements in the literature, was that different species accumulate lead and cadmium in different amounts. This fact is undoubtedly related to physiological as well as dietary differences. The five rabbits from East Helena that were eating the indigenous grasses showed a very high level of cadmium in kidneys, as shown in Table 6-1. The composite samples of Columbia ground squirrel kidneys also showed a moderate accumulation of cadmium (4.0 ppm). In contrast, the cadmium concentration of kidney composites of mice ranged from 1.5 to 14.0 ppm. From this evidence it is apparent that species in an area will be affected differently by a pollutant level, at least insofar as accumulation in body tissues is concerned. Thus, in estimating contamination of an ecosystem by means of evaluation of tissue concentrations, the tissue levels of the animal chosen for analysis must be compared to both normal and experimentally produced levels.

A second trend observed was that, in mice, accumulation of lead in the kidneys was many times greater than in the liver. This relationship was not evident in Columbia ground squirrels or in rabbits, where levels were more or less equal.

In mice from the East Helena area, lead levels in the liver ranged from 3.2 to 23 ppm and in kidneys from 8 to 110 ppm (fresh-weight basis).

The four rabbits from site 6 were domestic rabbits that had escaped; they had been eating the native vegetation for unknown periods of time. The rabbit from site 21 was a native rabbit, and the rabbit from site 14 was a domestic rabbit – a control selected to represent normal levels in rabbits. There is an obvious difference between the concentrations of metal found in the control rabbit and those found in the five rabbits eating indigenous vegetation in the East Helena area, especially in cadmium concentrations found in the kidneys.

The one pig assayed was one that died at site 6. Although the cause of death could not be defined, the bone lead level was 73 ppm.

In comparing the concentrations of lead and cadmium in rodent tissues and relating the levels to distance from the smelter, no definite correlation between concentrations of lead or cadmium in animals and distance from the ASARCO smelter stack is obvious. The highest levels of lead in rodent tissues were measured in samples from sites 1 and 9, two of the more distant collection sites, considering predominant wind direction. Tissue from sites 2 and 3, closer and in the same direction as sites 1 and 9, had lower lead levels. The lowest levels of

Table 6-2. ACCOUNTS OF SPECIES TAKEN IN EAST HELENA AREA, SUMMER 1969

Species	Remarks
Microtus pennsylvanicus (meadow mouse)	Food – Grasses and sedges, roots and bulbs. Stomach analysis–corn, barley, wheat, oats, clover, alfalfa, blue grass, broom sedge, bulrush, dock, strawberry, buttercup, goldenrod, rosin weed, ragweed, sunflower, willow, maple, poplar, oak, and apple. Habitat – Members of this subfamily *(Microtinae)* are found almost everywhere in the U.S. (with the exception of three southeastern states) where there is good grass cover. They are widely distributed from swamps to semibarren plains and from sea level to high mountains and are usually found in large numbers in meadows and grasslands. Discussion – The presence of *M. pennsylvanicus* may be detected by runways.
Peromuscus maniculatus (deer mouse)	Food – Seed, insects, berries, nuts in season, fruits, tubers, grains, and dry vegetable foods. Habitat – This nocturnal mouse is widely distributed from grasslands to forest. It is one of our commonest rodents south of the Arctic Circle. The home ranges vary from less than an acre for females up to roughly five acres for males. Discussion – The life span in the wild rarely exceeds 2 years. Almost complete annual turnover in the *P. maniculatus* population on the Edwin S. George Reserve in Michigan.
Mus musculus (house mouse)	Food – Almost anything man eats, partial to cereals and vegetable products Habitat – Cities or fields, waste places. *M. musculus* is found around human habitations and often in fields, especially grain fields. Discussion – Found wherever man's buildings are located.
Citellus columbianus (Columbian ground squirrel)	Food – Great variety of herbage, flowers, seeds, bulbs, fruits, some insects, nuts, grains, green vegetation, roots, young birds, and mammals. Habitat – Found in mountain meadows and grassy areas.

Table 6-2 (continued). ACCOUNTS OF SPECIES TAKEN IN EAST HELENA AREA, SUMMER 1969

Species	Remarks
	Discussion – Found in grassy areas where it can burrow. Normally found in colonies.
Eutamias amoenus (yellow pine chipmunk)	Food – Seeds, fruits, insects, berries, nuts, buds, etc.
	Habitat – Found primarily in the Yellow Pine Forests.
	Discussion – Lives in burrows underground.
Peromyscus leucopus (wood mouse)	Food – wide variety. Some insects
	Habitat – Deciduous forest. Woods and brushy areas. Varied.
	Discussion – Found in Eastern deciduous forests. Found in eastern Montana in wooded and brushy bottoms.
Microtus montanus (Montana vole)	Food – Grass and leaves.
	Habitat –Dry grassland and sagebrush-grassland.
	Discussion – Found in Rocky Mountains to the Sierra-Cascades. Population densities vary widely.
M. longicandus (longtail vole)	Food – Grass and leaves.
	Habitat – Wet areas in absence of *M. pennsylvanicus.*
	Discussion – Occupies altitudes from alpine to valley bottom. Found in eastern deciduous forests. Found in eastern Montana in wooded and brushy bottoms. Population density is usually low.
Sylvilagus nuttalii (mountain cottontail)	Food – Grass, shrub twigs, and bark. Most vegetation.
	Habitat – Shrubby gullies, forest edges, stream bottoms.
	Discussion – Found throughout Montana.
Oryctolagus cuniculus (domestic rabbit)	Food – Grass, shrub twigs, and bark. Most vegetation.
	Habitat – Seldom far from dwellings. Shrubby areas or woody edges.

Table 6-2 (continued). ACCOUNTS OF SPECIES TAKEN IN EAST HELENA AREA, SUMMER 1969

Species	Remarks
Lepus townsendii (white-tailed jack rabbit)	Food – Grass, shrub twigs, and bark. Most vegetation. Habitat –Grassland and sagebrush areas. Alpine areas of some mountain ranges. Discussion – Found in northwestern U.S. Less common west of the Continental Divide.

lead were found in rodent tissue from sites 5 and 22, two of the sites closest to the smelter. Obviously, for the mouse population, distance and wind direction are not the major factors in accumulation, at least within the distance surveyed.

In conjunction with the rodent-trapping project, soil and grass were collected from each site where rodents were trapped. The results of the analyses on these soil and grass collections are shown in Table 6-3.

Table 6-3. LEAD AND CADMIUM CONCENTRATIONS OF SOIL, GRASS, AND RODENT TISSUES

(ppm)

Rodent trapping site	Lead				Cadmium			
	Soil[a]	Grass[a]	Liver[b]	Kidney[b]	Soil[a]	Grass[a]	Liver[b]	Kidney[b]
1,9	600		15.0	110	23		0.4	2.0
2,3	1600	350	10.0	58	33	6	1.7	7.7
13,19,20	440		1.8	11	8		16.0	51.0
4,6	680	28	14.0	62	22	2	0.5	1.8
5,22	370	92	3.2	8	10	5	0.5	2.1
23,24,25		7[c]	4.7	53		1[c]	2.7	7.2
17,18	425	50	11.0	110	14	1	0.2	1.6
7,8,26	270	20	4.7	26	6	1	2.2	6.0
16		160	23.0	48		7	2.4	3.8
21			4.7	88			0.8	1.8

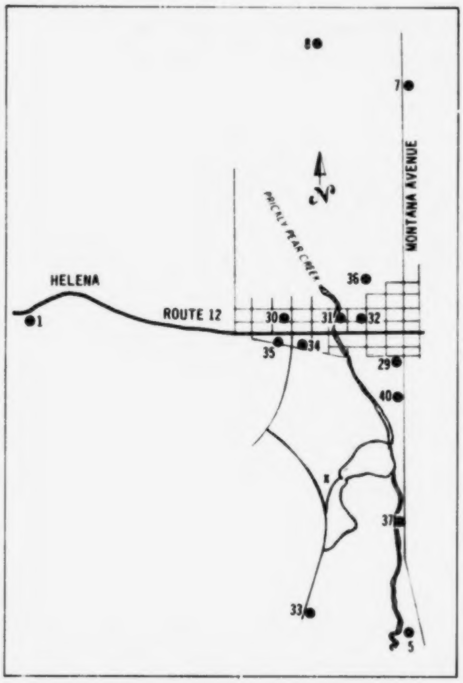
[a] Dry weight.
[b] Fresh weight.
[c] Alfalfa.

As an indicator of fallout from emissions from a single source, soil concentration should be the most accurate for long-range appraisal. Vegetation and animals should also reflect the fallout pattern. The soil concentrations of both lead and cadmium decrease in all directions from the ASARCO smelter stack. Topography and leaching would be two factors that might alter this pattern at some sites. For instance, soil taken from site 37 in September of 1968 and placed in frames at the University of Montana Botany Department gardens was assayed in October 1969 and compared with concentrations in soil taken directly from the East Helena site in October 1969. The transported soil had been watered routinely in the garden plot during the year. Lead and cadmium levels both had dropped during the year in Missoula, showing that irrigation and normal leaching can remove a substantial portion of soil levels of lead and cadmium.

The concentrations of lead and cadmium in grass also decrease with increasing distance from the stack.

LEAD AND CADMIUM IN GARDEN VEGETABLES

Vegetables, mainly lettuce, were gathered from gardens identified on the map in Figure 6-2 and analyzed for lead and cadmium. From each of the gardens from which lettuce was obtained, soil was taken for analyses for lead and cadmium. A comparison of metal contents of soil and of lettuce growing in that soil is shown in Table 6-4.



STATION	LOCATION
1	M V JOHNSON RESIDENCE
5	KLEFFNER RESIDENCE
7	ARMAGAST RESIDENCE
8	ARLIENT RESIDENCE
29	N J HELFERT RESIDENCE
30	PREBIL RESIDENCE
31	HILTNER RESIDENCE
32	GRANDY RESIDENCE
33	BUFF RESIDENCE
34	MEIHLE RESIDENCE
35	F MILLER RESIDENCE
36	LEV RESIDENCE
37	BESSLER RESIDENCE
40	LANE RESIDENCE
X	ASARCO STACK

Figure 6-2. Plant collection sites.

Table 6-4. LEAD AND CADMIUM CONTENT OF SOIL AND LETTUCE[a]

(ppm)

Site No.	Garden	Lead		Cadmium	
		Soil	Lettuce	Soil	Lettuce
1	Johnson	90	<10[b]	3	8[b]
35	Miller	840	250	18	16
30	Prebil	320	16[b]	8	13[b]
34	Meihle	1100	<10[c]	25	12[c]
31	Hiltner	550	26[b]	9	7[b]
8	Arlient	49	<10[b]	1	8[b]
7	Armagast	490	68	11	4
29	Helfert	1400	460	31	28
5	Kleffner	370	26	10	5
33	Buff	440	30	8	5
Missoula	Hughes garden	20	38	<1	<1
	Botany	20	12	<1	<1
	Dale	–	14	–	1.2
	Faculty	–	13	–	<1

[a] Dry weight.
[b] Leaves washed.
[c] Cabbage.

One lettuce and cabbage collection, that of June 28, 1969, was heavily splattered with soil due to a recent rain. The lettuce and cabbage leaves were thoroughly washed under cold running water in the lab and dried by blotting with cheesecloth. The washing and drying procedures were much more thorough than those customarily done in preparing leafy vegetables for table use; therefore, the amount of metal actually eaten would be greater than the analyses show. The amount of lead and cadmium indicated by the analyses would represent the amount contained in the tissues rather than that deposited on the leaf surfaces. A comparison of metal contents of lettuce from gardens, one collection washed and the other unwashed, appears in Table 6-5.

Table 6-5. COMPARISON OF WASHED WITH UNWASHED LETTUCE FROM THE SAME OR NEIGHBORING GARDENS[a]

(ppm)

			Lead		Cadmium	
Site No.	Gardens	Collection numbers	Unwashed	Washed	Unwashed	Washed
35,30	Miller, Prebil	63, 53	250	16	16	13
7	Armagast	68, 51[b]	68	<10	4	8
29	Helfert, N.J.	2,50	460	46	28	17
36,32	Lev, Grandy	67, 56	66	20	33	17
5	Kleffner	66, 57	26	26	5	14
33	Buff	64, 58	30	<10	5	12

[a] Dry weight.

[b] Cabbage.

Source of Lead and Cadmium in Garden Vegetables

Soil from some of the gardens was transported to Missoula so that a comparison could be made between lettuce grown in an atmosphere free of lead and cadmium and lettuce growing in air containing both metals. The results of the comparison are listed in Table 6-6. The sparseness and non-uniformity of the data prevent the assessment of the sources of metals in garden vegetables, i.e., whether from absorption of the metals from the soil through the roots or from the atmosphere through the leaf surfaces.

Table 6-6. HEAVY-METAL CONTENT OF LETTUCE GROWN IN EAST HELENA AND IN EAST HELENA SOIL TRANSPORTED TO MISSOULA[a]

(ppm)

		Lead		Cadmium	
Site No.	Location	East Helena	Missoula	East Helena	Missoula
5	Kleffner	26	9	5	3
34	Meihle	10	33	12	8
35, 37	Miller Bessler	250	32	10	28

[a] Dry weight.

UPTAKE OF CADMIUM AND LEAD FROM FOOD SOURCES

Twelve rabbits were involved in a feeding study for 6 weeks. The 12 were divided into three groups of four animals each. Two rabbits shared a cage; thus two cages were used for each group. Three breeds were used (New Zealand, Checkered Giant, and California), and all rabbits were within a few days of being

9 weeks old when the study began. Precautions were taken to avoid contamination of food or water by contact with metal containers. The animals were fed a commercial rabbit pellet (Ceretana*) in sufficient quantity to ensure good health. Concrete feeding dishes were used rather than the standard metal bins.

The rabbits were fed pellets each morning and fresh lettuce each evening. It was assumed that one rabbit would eat approximately half of the food placed in the two-rabbit cage. The amount fed daily was 86.6 grams of pellets and 100 grams of lettuce per rabbit. The quantity of lettuce fed was limited by the amount that could be expected to be available throughout the 6 weeks of the study. Lettuce was harvested weekly and kept in plastic bags in a cooler until needed.

Two groups of rabbits were fed lettuce thought to have high lead and cadmium concentrations. One group ate lettuce grown in East Helena gardens, and the other ate lettuce grown in Missoula on soil brought from East Helena and put into frames in the University of Montana botanical garden. Lettuce brought from East Helena was a composite from ten gardens (sites 1, 5, 7, 29, 30, 31, 32, 33, 35, and 36) (Figure 6-2). Samples of the rabbit pellet and of lettuce from both sources were analyzed as well as lettuce samples from the control gardens.

When the rabbits were sacrificed, one kidney and half of each liver was removed, placed separately in plastic bags, frozen, and forwarded to WARF Institute. A femur bone from each of the four rabbits being fed lettuce grown in East Helena was also sent for lead and cadmium analyses. Analyses on all these tissues were done at WARF as mentioned above. Results of these analyses are shown in Table 6-7.

The purpose of this study was to determine the accumulation patterns and differences for lead and cadmium in rabbits in cases where food was the source of the metals. Using lettuce from three different sources, supposedly representing different amounts of lead and cadmium, differences in total body accumulation were expected. Body accumulation was measured by tissue from the liver, kidney, and bone. Of the three lettuce sources, concentrations of lead and cadmium would be expected to decrease in this order: (1) East Helena, (2) Missoula with East Helena soil, and (3) Missoula. Group 1 would be expected to have accumulated excess metals via soil and air; group 2, via soil only; and group 3, neither.

The data on lead in liver and kidney indicate differences among groups 1, 2, and 3. The lettuce grown in Missoula in East Helena soil produced the highest accumulation of metals in tissue; the East Helena grown lettuce, the second highest; and Missoula lettuce, the third highest.

---

*Mention of a specific company or product does not constitute endorsement by the Environmental Protection Agency.

9 weeks old when the study began. Precautions were taken to avoid contamination of food or water by contact with metal containers. The animals were fed a commercial rabbit pellet (Ceretana*) in sufficient quantity to ensure good health. Concrete feeding dishes were used rather than the standard metal bins.

The rabbits were fed pellets each morning and fresh lettuce each evening. It was assumed that one rabbit would eat approximately half of the food placed in the two-rabbit cage. The amount fed daily was 86.6 grams of pellets and 100 grams of lettuce per rabbit. The quantity of lettuce fed was limited by the amount that could be expected to be available throughout the 6 weeks of the study. Lettuce was harvested weekly and kept in plastic bags in a cooler until needed.

Two groups of rabbits were fed lettuce thought to have high lead and cadmium concentrations. One group ate lettuce grown in East Helena gardens, and the other ate lettuce grown in Missoula on soil brought from East Helena and put into frames in the University of Montana botanical garden. Lettuce brought from East Helena was a composite from ten gardens (sites 1, 5, 7, 29, 30, 31, 32, 33, 35, and 36) (Figure 6-2). Samples of the rabbit pellet and of lettuce from both sources were analyzed as well as lettuce samples from the control gardens.

When the rabbits were sacrificed, one kidney and half of each liver was removed, placed separately in plastic bags, frozen, and forwarded to WARF Institute. A femur bone from each of the four rabbits being fed lettuce grown in East Helena was also sent for lead and cadmium analyses. Analyses on all these tissues were done at WARF as mentioned above. Results of these analyses are shown in Table 6-7.

The purpose of this study was to determine the accumulation patterns and differences for lead and cadmium in rabbits in cases where food was the source of the metals. Using lettuce from three different sources, supposedly representing different amounts of lead and cadmium, differences in total body accumulation were expected. Body accumulation was measured by tissue from the liver, kidney, and bone. Of the three lettuce sources, concentrations of lead and cadmium would be expected to decrease in this order: (1) East Helena, (2) Missoula with East Helena soil, and (3) Missoula. Group 1 would be expected to have accumulated excess metals via soil and air; group 2, via soil only; and group 3, neither.

The data on lead in liver and kidney indicate differences among groups 1, 2, and 3. The lettuce grown in Missoula in East Helena soil produced the highest accumulation of metals in tissue; the East Helena grown lettuce, the second highest; and Missoula lettuce, the third highest.

---

*Mention of a specific company or product does not constitute endorsement by the Environmental Protection Agency.

Table 6-7. LEAD AND CADMIUM CONTENTS OF RABBIT TISSUES[a]
(ppm)

	Diet of East Helena Lettuce					
	Lead			Cadmium		
Animal	Liver	Kidney	Bone	Liver	Kidney	Bone
1	0.1	0.3	5	<0.2	1	<1
2	0.1	0.3	16	<0.2	<1	<1
3	0.2	0.4	8	<0.2	1	<1
4	0.4	0.7	12	<0.2	1	<1

Diet of Lettuce Grown in East Helena Soil Transferred to Missoula

	Lead		Cadmium	
Animal	Liver	Kidney	Liver	Kidney
5	0.3	0.7	<0.2	<1
6	0.2	0.6	<0.2	<1
7	0.1	0.3	<0.2	<1
8	0.5	0.3	<0.2	<1

Diet of Hughes Garden Lettuce, Missoula (Control)

	Lead		Cadmium	
Animal	Liver	Kidney	Liver	Kidney
9	0.1	0.3	<0.2	<1.0
10	0.1	0.2	<0.2	<0.3
11	0.1	0.3	<0.2	<0.5
12	0.3	0.2	<0.2	<0.2

[a] Fresh weight.

Liver levels of cadmium for all three groups were less than 0.2 ppm. In group 1, three rabbits had kidney levels of 1 ppm, and all rabbits in groups 2 and 3 had less than 1 ppm. In group 3, two rabbits had concentrations of 0.3 and 0.5 ppm, and one had less than 0.2 ppm. The difference in threshold of readings in the three rabbits of group 3 may be misleading, however, because the readings of less than 1 ppm for the other rabbits may actually signify concentrations as low as or lower than the 0.3 and 0.5 values.

It is apparent, therefore, that for the given length of feeding, quantity of lettuce fed, and concentration of lead and cadmiun in the lettuce, only small differences in accumulation occurred among the groups, and total accumulation was insignificant. Since bone lead of groups 2 and 3 was not assayed, direct comparison of the three groups on this point is impossible and comparison may be made only with the literature.

The concentration of lead and cadmium in the lettuce was an important variable. Lettuce from one garden varied in metal concentration from week to week; in East Helena, lettuce from the many gardens used as a source of lettuce for group 1 varied considerably (less than 10 to 460 ppm). Lettuce from Hughes Garden (control area) in Missoula (group 3) assayed at 38 ppm lead (100 yards from the Interstate highway), and lettuce grown on East Helena soil transported to Missoula contained 32 ppm lead. The source of lead in the Hughes Garden lettuce has not been identified, but insecticide foliar sprays and automobile exhaust are suspected as likely sources.

A much longer feeding time and increased daily consumption of lettuce by the group of rabbits would be required to determine if significant accumulation differences actually exist. Also, lettuce for each group should be obtained from gardens containing similar concentrations of these two metals.

CONIFER FOLIAGE INVESTIGATIONS

Sulfur and Lead Content

During October 1969, needle collections were taken for chemical analyses from conifers growing in the East Helena area. All needles emerging in 1968 and 1969 (and some in 1967) were sent to WARF for total sulfur analysis. A few samples of 1968 and 1969 needles (and one of 1967 needles) were sent for lead analysis.

Needles emerging from the bud in the spring of 1968 were formed during the summer of 1967 and remained in a primordial form enclosed by thick protective bud scales during the winter. During the rapid spring growth of 1968, the needle primordia enlarged, thrusting aside the protective bud scales. One year's needles are separated from another by the bud scales left clinging to the stem. Using this information, the age of a needle may be determined by counting the rings of terminal bud scale scars from the branch tip to the needle. The collection sites, tree species, year of needle emergence, and results of analyses are listed in Table 6-8.

A change in sulfur and lead content occurred during the period 1967 to 1969. Both lead and sulfur levels were greater in 1968 than in 1967; then both decreased in 1969. In the case of sulfur, the analysis for total sulfur represents the amounts assimilated into the conifer needle and that which accumulated on the surface. Due to an increase in the percentage of sulfur in ores smelted and in production capacity, the emissions of the ASARCO smelter in East Helena increased during the late summer of 1967. Thus the conifer needles emerging in May of 1967 had their most vigorous growing period before the increased smelter emissions. The sulfur level for the 1967 needles can consequently be considered as arising in large part from the sulfur accumulating upon the needle surface from the fall of 1967 to the fall of 1969 (a 2-year period). In contrast, the needles emerging in the spring of 1968 were exposed to high sulfur dioxide levels during their most active growing stage and, thus, incorporated more sulfur into their tissues. Surface accumulation of sulfur also occurred subsequently.

Because the 1968 levels of sulfur dioxide had caused damage to vegetation the lead assayed was that which was assimilated into the tissues and did not include lead deposited on the needle surface; if lead were accumulating on the needle surface, the 1967 needles would be expected to have more than 40 ppm lead after 2 years of exposure.

Histological Examinations

On July 26, 1968, 3-year-old seedlings of *Pinus ponderosa* and *Pinus Sylvestris* were planted in four locations. Two of the four conifer plots that had been planted in 1968 had been destroyed. One of those was located at Bessler's home (800 yards southeast from the ASARCO stack) and the other at Marche's (1800 yards southwest from the ASARCO stack). Bessler's plot was destroyed when ASARCO moved Bessler's house off the property and filled and leveled the ground where the basement had been. The plots at Marche's were destroyed because they were not watered or maintained. At the Meihle residence (approximately 700 yards north of the ASARCO stack), three ponderosa pines and three lodgepole pines were planted in May 1969.

Collections of conifer foliage for histological studies were made at three locations during October 1969. These locations were at the residences of Miller (approximately 500 yards northwest of the ASARCO stack), Meihle (700 yards northeast from the stack), and Kleffner (1800 yards southeast of the stack). At Miller's house, needles were taken from a 2-foot-high scotch pine tree. At Meihle's, needles were taken from the ponderosa, lodgepole, and scotch pine seedlings that had been planted in 1968 and 1969. At Kleffner's house, collections were taken from trees planted in 1968 and also from a damaged alpine fir and an Engelmann spruce in his front yard.

Selected pine needles from each of the three sites were prepared for histological studies through the paraffin method, and photomicrographs were taken to depict the disease syndrome manifested in the needle tissues.

The following phenomena were seen in the photographs of needles from East Helena.

1. The mesophyll cell below the stomatal opening was almost invariably destroyed. This cell was either ruptured, collapsed, or completely disintegrated by the time the thin-walled cells of the vascular system were undergoing hypertrophy.

2. The chloroplast and nuclei within the mesophyll cells were destroyed, causing the cells to have a granular appearance.

3. The epithelial cells of the resin canals underwent hypertrophy and, if collapse did not occur, their enlarged cells became thick-walled and rigid.

4. The inner walls of the endodermal cells collapsed, and the thicker, outer walls rarely, if ever, collapsed.

5. The parenchymatous cells of the transfusion tissue, which lie between the two vascular bundles, underwent tremendous hypertrophy and then collapsed, leaving a large area devoid of cells.
6. The albuminous parenchyma cells of the phloem tissue as well as those from the inactive phloem (the three to five layers from the xylem cells) underwent hypertrophy and then collapsed.

All of the above disease symptoms manifested by the various cells and tissues of the conifer needles indicate sulfur dioxide damage in East Helena. The same symptoms occurred within the tissues of ponderosa pine needles that underwent controlled fumigation tests with sulfur dioxide.

The disease syndrome is identical to that observed in 1968 in conifer needles from East Helena. The amount of damage to conifer needles was greatly reduced during 1969, a reduction that can be attributed to the shutdown of the ASARCO smelter during the most sensitive growth period of the conifer needles (June 1969), as well as to the decreased production at this plant until September 1969.

BIBLIOGRAPHY FOR CHAPTER 6

Allison, R. V. and Thomas Whitehead, Jr. Know Fertilizer Materials Better: Trace Elements in Some Organic Fertilizers. Florida Grower. Jan. 1943. p. 4.

Axelsson, Bengt and Mangus Piscator. Renal Damage After Prolonged Exposure to Cadmium. Arch. Environ. Health. *12*:360-373. 1966.

Bates, F. Y., D. M. Barnes, and J. M. Higbee. Lead Toxicosis in Mallard Ducks. Bull. Wildlife Disease Assoc. *4*:116-125. 1968.

Cannon, Helen L. and Jessie M. Bowles. Contamination of Vegetation by Tetraethyl Lead. Science. *137*:765-766. 1962.

Carroll, Robert E. The Relationship of Cadmium in the Air to Cardiovascular Disease Death Rates. JAMA. *198*:177-179. 1966.

Hopkins, Homer and Jacob Eisen. Mineral Elements in Fresh Vegetables from Different Geographic Areas. Agric. and Food Chem. *7*:633-638. 1959.

Hopkins, Homer, E.W. Murphy, and D. P. Smith. Minerals and Proximate Composition of Organ Meats. J. Amer. Dietic. Assoc. *38*:344-349. 1961.

Joseph, Glenn H., Jesse W. Stevens, and John R. MacRill. Nutrients in California Lemons and Oranges. J. Amer. Dietic. Assoc. *38*:552-559. 1961

Klein, A. K. and H. J. Wichmann. Report on Cadmium. Assoc. Official Agric. Chem. J. *28*:257-269. 1943.

Krehl, Willard A. and George R. Cowgill. Nutrient Content of Cane and Beet Sugar Products. Food Res. *20*:449. 1955.

Locke, L. N., H. D. Irby, and G. E. Bagley. Histopathology of Mallards Dosed with Lead and Selected Substitute Shot. Bull. Wildlife Disease Assoc. *3*:143-147. 1967.

Locke, L. N. et al. Lead Poisoning and Aspergillosis in an Andean Condor. JAVMA. *155*:1052-1056. 1969.

McCance, R. A. and E. M. Widdowson. The Composition of Foods. Medical Research Council SRS 297. Her Majesty's Stationery Office, London. 1967.

McKee and Wolf. Water Quality Criteria, 2nd Ed. The Resources Agency of California. State Water Quality Control Board, Sacramento, California, Pub. No. 3-A.

Schroeder, Henry A. Cadmium Hypertension in Rats. Am J. Physiol. *207*:62-66. 1964.

Schroeder, Henry A. Cadmium as a Factor in Hypertension. J. Chron. Dis. *18*:647-656. 1965.

Schroeder, Henry A. Cadmium, Chromium, and Cardiovascular Disease. Circulation. *35*:570-582. 1967.

Schroeder, Henry A. et al. Hypertension in Rats from Injection of Cadmium. Arch. Environ. Health. *13*:788-789. 1966.

Schroeder, Henry A. and Jeffrey Buckman. Cadmium Hypertension: Its Reversal in Rats by a Zinc Chelate. Arch. Environ. Health. *14*:693-697. 1967.

Schroeder, Henry A. et al Influence of Cadmiun on Renal Ischemic Hypertension in Rats. Amer. Jour. Physiology. *214*:469-474. 1968.

Schroeder, Henry A. et al. Action of a Chelate of Zinc on Trace Metals in Hypertensive Rats Amer. Jour. Physiology. *214*:796-800. 1968.

Smith, J. P. and A. J. McCall. Chronic Poisoning from Cadmium Fume. J. Path. Bact. *80*:287-296. 1960.

Von Oettingen, W. F. Poisoning: A Guide to Clinical Diagnosis and Treatment. W. B. Saunders Co., Philadelphia. 1958.

Warren, Harry V. Some Aspects of Lead Poisoning in Perspective. J. Coll. Gen. Practit. *11*:135-142. 1966.

Warren, Henry V. and Robert E. Delavault. Observations on the Biogeochemistry of Lead in Canada. Transactions of the Royal Society of Canada. *54*:11-20. 1960.

Warren, Henry V. and Robert E. Delavault. A Geologist Looks at Pollution: Mineral Variety. Western Miner. Dec. 1967.

Warren, Henry V. and Robert E. Delavault. Lead in Vegetables. Reproduction of a letter to the Editor published in the Lancet. p. 1252. June 8, 1968.

7. EFFECTS OF AIR POLLUTION ON LIVESTOCK AND ANIMAL PRODUCTS

Trent R. Lewis, Ph.D.

ENVIRONMENTAL PROTECTION AGENCY
National Environmental Research Center

This study was conducted to assess the effects of air pollution on livestock and consumable products derived from livestock. Two questions were of significance: (1) what was the primary effect of air pollution on the health of the livestock *per se?* and (2) what was the health hazard to humans who ingested meat, milk, and eggs from such farm animals?

EFFECTS ON LIVESTOCK

Interviews with farmers, veterinarians, and the Montana Livestock Sanitary Board revealed that horses were markedly more susceptible than other species of farm animals to environmental toxicants in the Helena Valley. As a result, portions of the manes of 39 horses were clipped at 13 farm sites for future quantification of their lead, cadmium, zinc, and arsenic contents. Hair is a depot for lead, cadmium, and arsenic during long-term exposure to these toxicants. Because hair and other epidermal structures normally have a high zinc content, they are less reliable.in assessing chronic intoxication from zinc.

It is difficult to interpret the results of such a survey because horses are frequently moved from one pasture to another. Meteorological conditions, particularly prevailing wind direction, largely determine the level of exposure to air pollutants; lushness of the vegetation present and the grazing and watering habits determine exposure levels due to ingestion.

Methods

Sample Collection

Two persons visited 12 farm sites to collect hair samples from horses. Horses were housed in pastures at 9 of these sites, in corrals at 2 sites, and in a barn at 1 site. Each rancher willingly volunteered hair samples from every horse at each site; at approximately half of the sites, the rancher gave assistance. There was only one site at which the total horse population could not be sampled – site 5. In this case, two horses were in a large pasture and only one could be approached and would stand still while a sample of mane was collected.

One person stood at the head of each horse and controlled the horse while the second person took two to three handfuls of mane and cut each handful with heavy scissors. These samples, which weighed between 6 and 20 grams, were placed in plastic bags; the bag was tied off, and an identification tag containing relevant comments was attached to each.

Animal products were collected at five sites in East Helena where chickens or lactating dairy cows were housed or, in one case, where home slaughtering had occurred. In addition, a rabbit that had been dead for approximately 1 to 2 hours and showed no evidence of accidental or predatory cause of death was collected for examination.

Sample Preparation

Two- to six-gram samples of horse hair were weighed and cleaned. Cleaning entailed successive washings with acetone, ethyl ether, and acetone. Time of contact was 10 to 15 minutes for each washing, accompanied by agitation from time to time by hand or stirring rod. After the last acetone wash was decanted, about 150 milliliters (ml) of a 0.75 percent commercial detergent solution was added. Time of contact was about 15 minutes, also with stirring. Then the hair was washed free of detergent with tap water, placed on filter paper, and rinsed four times with deionized distilled water, and then with acetone. The hair was dried for 2 to 4 hours at 90° to 100° C and then weighed.

Digestion

Hair samples were placed in digestion flasks and heated gently on a hot plate. Portions of redistilled nitric acid were added, beginning with 10 ml and decreasing as the digest decreased in volume and the temperature increased. When the digest was yellow, 1 to 2 ml of nitric acid and 0.5 ml of 70 percent perchloric acid were added to complete digestion. The acid mixture was evaporated off until the flask was just moist. When cool, the residue was taken up in water and about 0.5 ml of concentrated redistilled nitric acid was added. Final volume in all cases was 25.0 ml.

Analysis for Lead

In general, 10-ml aliquots were taken for analysis by chelation extraction and solvent concentration. Dilutions of samples of 30 ml volume were adjusted to a pH of 2.28 to 2.34. One milliliter of 1 percent chelating agent, ammonium pyrrolidine dithiocarbamate, was added to a 60 ml separatory funnel, and the sample solution was poured in. A quantity of 5.0 ml of solvent, methyl isobutyl ketone, was pipetted in and each flask was shaken for 2 minutes. After about 5 minutes, the lower aqueous phase was discarded, and solvent was collected for centrifugation at 2500 rpm for 10 minutes. The solvent was aspirated into the atomic absorption apparatus, and lead concentration was determined by comparison of absorption with similar lead standards.

Analyses for Other Elements

One milliliter was taken of the 25 ml of acid digest and diluted to bring the zinc concentration to between 1 and 2 micrograms per milliliter. On most samples, 1 ml of sample was added to 20 ml of water. Sample dilutions were aspirated directly into the atomic absorption spectrophotometer, and absorption of samples was compared with standards in aqueous solution. Aliquots of the previous acid sample digest were analyzed by atomic absorption spectrophotometry for cadmium and arsenic in the same manner as described for lead and zinc.

Results

A geographic orientation of the sampling sites is presented in Table 7-1. This orientation is based upon an angular displacement from the north-south meridian passing through the smoke stack of the American Smelting and Refining Company at East Helena, Montana. Angular measurements are clockwise, originating at the north and increasing to east, south, and west, and returning to north. Distances from the stack are also recorded. Arsenic, zinc, cadmium, and lead concentrations in the manes of the 39 horses sampled are found in Table 7-2. Duplicate analyses and their means are presented for each of the four elements, and a site mean has also been computed. Since the sensitivity of the assay method (atomic absorption) used to determine arsenic content was 2.0 μg/g, sample duplicates and mean values of the elements are difficult to compare. Detection of measurable arsenic is merely indicative of exposure to arsenic; toxicity can be determined only on the basis of absolute levels.

Table 7-1. COLLECTION SITES FOR HORSE MANE SAMPLES

Site	Compass		Distance from stack, mi
	Direction	Degrees	
1	SSE	160	1.0
2	E	85	2.9
3	SE	110	2.6
4	SE	122	5.3
5	NE	30	2.9
6	NNW	338	2.3
7	NNW	344	1.9
8	N	355	1.0
9	NW	330	1.4
10a	WNW	285	2.3
10b	WNW	286	7.6
11	W	278	3.0
12	E	95	4.7

Table 7-2. ANALYSES FOR ARSENIC, ZINC, CADMIUM, AND LEAD IN HORSE-MANE HAIR

(μg/g)

		Arsenic		Zinc		Cadmium		Lead	
Site	Horse	Sample	Avg	Sample	Avg	Sample	Avg	Sample	Avg
1	Brown stallion	6.5 5.3	5.9	230 210	220	2.3 2.7	2.5	4.2 7.2	5.7
1	Black and white Welsh mare	7.5 3.7	5.6	220 220	220	1.9 2.3	2.1	11.2 13.8	12.5
1	Palomino gelding	2.1 0	1.0	240 240	240	3.6 1.8	2.7	6.6 5.3	6.0
			4.2		230		2.4		8.1
2	Bay gelding	0		210 200	200	1.8 2.2	2.0	4.3 4.6	4.4
2	Bay mare	0		210 260	240	0.8 0.6	0.7	2.0 2.6	2.3
2	Bay mare[a]	4.4 0	2.2	280 220	250	1.0 0.9	1.0	4.5 3.0	3.8
2	Palomino mare	0		240 240	240	2.0 1.6	1.8	15.6 12.1	13.8
2	Bay mare	3.1 0	1.6	210 250	230	1.7 1.7	1.7	4.6 3.0	3.8
2	Bay mare	0		300 350	320	1.1 1.2	1.2	4.9 3.4	4.2
2	Bay mare	0		430 420	420	1.7 1.6	1.6	4.6 5.2	4.9
2	Shetland gelding	0		230 210	220	1.3 1.8	1.6	3.1 4.1	3.6
2	Bay gelding	0		300 380	340	1.4 1.5	1.4	4.8 2.8	3.8
2	Sorrel gelding	0		370 400	380	1.0 1.1	1.0	5.5 3.9	4.7
2	Black gelding	0		210 190	200	0.6 2.3	1.4	8.0 6.7	7.4
			0.34		280		1.4		5.2
3	Sorrel gelding	0		250 230	240	1.8 1.5	1.6	9.8 14.8	12.3
3	Bay mare	0		380 340	360	4.6 3.6	4.1	25.8 22.2	24.0
			0		300		2.8		18.2
4	Bay gelding	0		180 170	170	0.9 1.0	1.0	9.0 6.7	7.8

Table 7-2 (continued). ANALYSES FOR ARSENIC, ZINC, CADMIUM, AND LEAD IN HORSE-MANE HAIR

(µg/g)

Site	Horse	Arsenic		Zinc		Cadmium		Lead	
		Sample	Avg	Sample	Avg	Sample	Avg	Sample	Avg
4	Appaloosa mare	0		170 200	180	0.8 0.7	0.8	5.5 4.3	4.9
4	Shetland pony	0 2.3	1.1	190 190	190	2.4 1.9	2.1	10.6 11.9	11.2
4	Black gelding	0		200 200	200	0.6 0.7	0.7	4.4 3.4	3.9
4	Bay gelding	0		200 180	190	0.5 0.5	0.5	7.0 5.5	6.3
			0.2		190		1.0		6.8
5	Bay mare	0		220 190 180 190	200	8.4 9.6	9.0	32.6 37.6	35.1
			0		200		9.0		35.1
6	Bay gelding	0		180 230	200	0.3 0.3	0.3	0.8 1.6	1.2
6	Black gelding	0		140 190	160	0.2 0.3	0.2	0.7 0.9	0.8
6	Brown gelding	0		180 190	190	0.3 0.3	0.3	1.1 2.5	1.8
6	Buckskin gelding	0		200 190	200	0.6 0.3	0.4	1.7 1.8	1.8
			0		190		0.3		1.4
7	Bay gelding	0		210 220	210	1.3 1.4	1.4	11.1 9.6	10.4
			0		220		1.4		10.4
8	Sorrel mare	4.5 0	2.3	240 260	250	2.3 2.2	2.3	9.8 9.8	9.8
8	Bay mare	0 3.2	1.6	230 210	220	1.7 2.6	2.2	8.0 5.3	6.6
8	Bay mare	0		200 180	190	3.0 1.3	2.2	6.4 5.1	5.8
			1.3		220		2.2		7.4
9	Roan mare	0		200 200	200	1.5 1.5	1.5	13.8 15.6	14.7
9	Sorrel gelding	0		250 210	230	2.8 3.0	2.9	6.1 11.9	9.0
			0		220		2.2		11.8

Table 7-2 (continued). ANALYSES FOR ARSENIC, ZINC, CADMIUM, AND LEAD IN HORSE-MANE HAIR

(μg/g)

Site	Horse	Arsenic		Zinc		Cadmium		Lead	
		Sample	Avg	Sample	Avg	Sample	Avg	Sample	Avg
10a	Bay gelding	0	0	190 210	200 200	0.7 0.9	0.8 0.8	3.9 2.8	3.4 3.4
10b	Chestnut sorrel	0		250 240	240	1.4 1.1	1.2	9.5 6.3	7.9
10b	Black and white mare	0	0	220 220	220 230	1.5 1.4	1.4 1.3	6.9 5.4	6.2 7.0
11	Sorrell gelding	0		240 230	240	0.7 0.6	0.7	3.0 2.8	2.9
11	Bay gelding	0		200 200	200	1.4 1.3	1.4	5.1 4.8	5.0
11	Palomino pony	0	0	200 220	210 220	0.9 5.3	3.1 1.7	5.8 3.0	4.4 4.1
12	Bay mare	0	0	220 210	220 220	1.1 0.8	1.0 1.0	3.5 2.8	3.2 3.2

[a] Died October 12, 1969.

One method of biological evaluation would be to compare data found in Tables 7-1, 7-2, and 7-3. Table 7-3 ranks the sites of collection from the highest to lowest concentration of each element within the mane. Such a comparison reveals that horses located at sites 1, 3, 5, 7, 8, and 9 (sites near the smelter) had high cadmium and lead concentrations. The single horse that represented site 5 had twice the lead concentration of any other horse in the study. Four of the six sites are within 2 miles of the smelter stack, and the other two are within 3 miles. Prevailing summer daytime winds at sites 1 and 3 are west to east. Sites 5, 7, 8, and 9 are located in areas where the prevailing summer nightime winds blow from south to north. Cadmium and lead levels in soil and vegetation samples were high at five of the six sites; the exception was site 5. The extremely high cadmium and lead levels in the mane from the horse at site 5 probably reflect husbandry practices in which the animal depended primarily on sparse pasture for food.

Horses at site 6 are unique in that they are never permitted to graze pasture, but are fed hay shipped in from a location outside the Helena Valley. Furthermore, these horses are stabled 2.3 miles from the smelter, a shorter distance from the smelter than sites 3 and 5. These animals were selected as the local control population for comparison with horses at other sites and under different

Table 7-3. RANKING OF SITES BY AVERAGE METAL CONTENT OF HORSE MANE

Arsenic		Cadmium		Zinc		Lead	
Site	Content, µg/g	Site	Content, µg/g	Site	Content, µg/g	Site	Content, µg/g
1	4.2	5	9.0	3	300	5	35.0
8	3.9	3	2.9	2	280	3	18.0
2	0.3	1	2.4	10b	230	9	12.0
4	0.3	9	2.2	1	230	7	10.0
3	0.0	8	2.2	8	220	1	8.0
5	0.0	11	1.7	9	220	8	7.4
6	0.0	2	1.4	12	220	10b	7.1
7	0.0	7	1.3	11	210	2	5.2
9	0.0	10b	1.3	7	210	4	4.8
10a	0.0	12	1.0	5	210	11	4.1
10b	0.0	4	1.0	10a	200	10a	3.4
11	0.0	10a	0.8	4	190	12	3.2
12	0.0	6	0.3	6	190	6	1.4

husbandry practices. One will notice the low and uniform cadmium and lead levels in the manes of these horses. Of the horses studied at all 13 sites, these animals rank lowest in both lead and cadmium concentrations in the mane.

Zinc concentrations ranked similar to those for cadmium and lead in that horses at four sites had the highest concentrations of zinc and also had the highest concentrations of cadmium and lead (sites 1, 3, 8, and 9). The range of zinc concentrations was approximately twofold. Horses at site 6 also had lowest zinc concentrations. Because horse mane, however, normally contains high concentrations of zinc and because zinc is usually not considered to be a highly toxic metal, zinc appears to be no health hazard to horses in the East Helena area.

Significant arsenic levels were detectable in horses housed at sites 1, 2, and 8. Sites with high arsenic levels, 1 and 8, correspond to higher-ranked cadmium and lead concentration levels shown in Table 7-3. Furthermore, five of the six horses housed at these two sites had detectable arsenic concentrations; the one exception was a young mare that was fed hay in the corral and was never allowed to graze. Although arsenic was detected in only 2 of 11 horses at site 2, one of the 2 subsequently died.

Table 7-4 contains histories and pertinent comments on the 39 horses in the survey. A comparison of Table 7-4 with data contained in the other tables implies that older animals, animals residing in the Valley for the longest duration, and chronically impaired animals had higher concentrations of lead and cadmium in their manes. On the other hand, horses that had no access to pastures for grazing had the lowest concentrations of lead and cadmium in their manes.

Table 7-4. **FIELD NOTES ON HORSES SAMPLED**

Site	Horse	Mane color	Age, yr	Time at site,[a] yr	Comments
1	Brown stallion	Light brown	2	1	Hay from outside; slight grazing
1	Black and white Welch mare	Black	15	6	
1	Palomino gelding	Yellow	4	1	
2	Bay gelding	Black	12	12	
2	Bay mare	Black	4	4	
2	Bay mare[b]	Black	3	3	Sick last 6 mo; worse last 2 mo
2	Palomino mare	Yellow	34	2	
2	Bay mare	Black	5	5	
2	Bay mare	Black	10	10	
2	Bay mare	Black	30	17	13 yr in hills this side of mountains
2	Shetland gelding	Black	11	2	
2	Bay gelding	Black	9	5	
2	Sorrel gelding	Black, gray-brown mixed together	8	5	
2	Black gelding	Black	11	11	
3	Sorrel gelding	Brown	20	15	
3	Bay mare	Black	20	7	Wind problems
4	Bay gelding	Black	8	5	
4	Appaloosa	Black	3	3 mo	3 yr at fairground
4	Shetland pony	Gray	6	4	
4	Black gelding	Black and gray	5	3 mo	2 yr SE of here in mountain
4	Bay gelding	Dark brown	18	10	
5	Bay mare	Black	1.5	1.5	
6	Bay gelding	Black	10	3	
6	Black gelding	Black	7	2	
6	Brown gelding	Black	12	3	
6	Buckskin gelding	Brown	28	16	
7	Bay gelding	Brown	15	5	At Billings before here. Owner says horse is smoked.
8	Sorrel mare	Brown	20		In mountains 15 miles east of smelter most of time. Had since was a colt.

Table 7-4 (continued). FIELD NOTES ON HORSES SAMPLED

Site	Horse	Mane color	Age, yr	Time at site,[a] yr	Comments
8	Bay mare	Black	12	5	Here in summer, out in winter. Purchased in 1964.
8	Bay mare	Black	3		Always in corral, eats home-grown hay
9	Roan mare	Brown	7-8	5-6	Stifled.
9	Sorrel gelding	Brown	17-20	5-6	
10a	Bay gelding	Black	7	7	In pasture off main road.
10b	Sorrel gelding	Black	6-8	7	
10b	Black and white mare	Black	10	10	
11	Sorrel gelding	Brown	7	1 mo	
11	Bay gelding	Black	7	1 mo	
11	Palomino pony	White	1	2-3 mo	Eats hay from Site 8.
12	Bay mare	Black	15	15	Born and raised on premises.

[a] Years unless indicated otherwise.
[b] Died October 12, 1969.

One animal merits special attention because it was sick during the period of sample collection and died shortly thereafter. This animal was a 3-year-old bay mare that had lived at site 2 for its entire lifespan. The owner stated that the animal had been sick for approximately 6 months and became noticeably dyspneic during the last 2 months preceding death. Table 7-5 summarizes elemental analyses performed on specific organs by the Montana Livestock Sanitary Board (MLSB), FDA laboratory in Denver, Colorado, and NAPCA personnel in Cincinnati, Ohio.

The postmortem report prepared by the local veterinarian read:

> 10/12 – about 4 pm on horse reported to have clinical signs of "smoked" horse syndrome. Frothy nasal exudata, congestion and consolidation in lungs with varying degrees of hepatization, grossly; not the severity of lung damage as seen in some previous cases on ranch. All other systems (no nervous exam) appeared grossly normal.

Table 7-5. POSTMORTEM ORGAN ANALYSES OF HORSE, SITE 2[a]

(μg/g)

Organ	As	Pb	Cd	Zn	Authority
Lung	0.7	0.3	1.6	14.0	FDA
	0	0.4	0.6	56.0	NAPCA
Liver	0.1	5.0	80.0	135.0	FDA
	Negative	4.0			MLSB
Kidney	Trace	4.0	410.0	142.0	FDA
	0	2.4	228.0	85.0	NAPCA
Flank muscle	0.11	0.08	3.9	68.3	FDA
Mane hair	2.0	3.8	1.0	240.0	NAPCA
Heart	0	2.0	0.4	6.5	NAPCA
Spleen	0	0.3	4.1	36.0	NAPCA
Bone	0	66.5	1.0	65.0	NAPCA

[a] Wet weight.

Conclusions

Proximity to the stacks of the American Smelting and Refining Company and the Anaconda Company correlates with increased levels of arsenic, lead, and cadmium in the manes of horses. Such findings are consistent with the results of soil and vegetation analyses for the area. Furthermore, older animals, animals residing in the Valley for the longest duration, and chronically impaired animals had high concentrations of lead and cadmium in their manes. On the other hand, horses that had no access to pastures for grazing had the lowest concentrations of lead and cadmium in their manes. Control horses from site 6 had no detectable arsenic, 1.4 μg of lead/g, 0.3 μg of cadmium/g, and 190 μg of zinc/g. No baseline values for these elements in horsehair could be found in the existing literature. In reviewing the elemental content of the manes of these horses, however, 50 percent of the horses at sites investigated showed lead and cadmium levels two to five times greater than the values found in the control horses.

The arsenic levels that were detected are indicative of exposure to arsenic; however, the toxicologic significance of these levels remains unclear. Arsenic concentrations tend to increase with increasing zinc, cadmium, and lead levels in hair. Zinc is considered to be a metal with minimal toxic properties; zinc poisoning in animals is a very controversial subject because of the variable results in experimental studies. The range of levels of zinc in the manes of horses in this study does not appear to suggest exposure to toxic levels.

The horse from which postmortem data are presented had highly toxic levels of cadmium and lead in the kidney and liver; these levels were not reflected in the mane. This disparity probably relates to an acute exposure to these metals rather than a long-term or chronic exposure. The level of 4 μg of lead per gram of liver tissue reflects lead poisoning, the normal concentration being 0.04 μg/g. The postmortem report on the lung is consistent with chronic lead and/or cadmium exposure, pneumonia primary or secondary to heavy-metal exposure, and/or heart disease primary or secondary to heavy-metal exposure.

CONTAMINATION OF LIVESTOCK PRODUCTS

In conjunction with the Denver laboratory of the Food and Drug Administration, a protocol was evolved to assess the health hazards to humans of foodstuffs derived from the indigenous animal population. This protocol sought the collection of the following four types of biological samples:

1. Samples, 50 to 100 grams each, of kidney, liver, and muscle collected from 10 beef cattle and 10 swine from each of the four compass points relative to the American Smelting and Refining Company smelter; preferably all samples for each point were to be within a 1-mile radius of each other and between 0 and 5 miles from the smelter.

2. One mile sample, 50 cubic centimeters, from each lactating dairy cow that could be found in the East Helena area, up to a maximum of 10 samples.

3. Egg samples from chickens in the East Helena area, up to a maximum of 10 egg samples from 10 different sites.

4. Kidney, liver, and muscle samples, 50 grams, from any seriously sick domestic or wild animal in the East Helena area.

The domestic animal population in the East Helena area is small, not uniformly distributed, and migratory in nature. The majority of the animals, notably beef cattle and horses, are in the distant mountain pastures in the summer months and proximate to the ranches during the winter. Collection of the aforementioned samples was complicated further when the opening of the local slaughter house was delayed from October 1969 to January 1970. Thus, all potentially edible foodstuffs of animal origin were limited to those that could be collected from local farms either as egg or milk samples or to those that could be obtained immediately following home slaughtering. Unfortunately, these samples amounted to chicken, rabbit, milk, beef, and pork samples from five different farm sites. The sampling locations and results are presented in Table 7-6. The angular degrees and distances from the stack are computed in the same manner as for Table 7-1.

Samples were analyzed for all metals except arsenic by the FDA laboratory in Denver, Colorado, using procedures of wet ashing and atomic absorption spectrophotometry. Samples to be analyzed for arsenic were ashed in a muffle furnace at 550° C for 2.5 hours and quantitated by arsine distillation into silver diethyldithiocarbamate. The resulting complex was measured spectrophotometrically at 540 nanometers.

Table 7-6. SELECTED METAL CONTENTS OF MISCELLANEOUS ANIMAL PRODUCTS[a]

(μg/g)

Specimen	Distance from stack,		As	Pb	Cd	Zn
	degrees	miles				
Chicken (muscle)	327	1.1	Trace	0.1	0.06	5.5
Rabbit (muscle)	112	0.4	0.6	0.5	0.2	12.0
Whole milk	287	1.8	Trace	0.06	0.02	4.9
Beef tissue (liver)	197	1.9	0.2	0.2	0.2	69.5
Beef tissue (muscle)	197	1.9	0.05	0.4	0.4	27.0
Beef (knee bone)	133	0.6	0	20.0	1.4	58.0
Swine tissue (heart)	197	1.9	Trace	0.1	0.1	19.0
Sausage	197	1.9	Trace	0.1	0.1	18.0

[a] Wet weight.

8. TRACE-METAL CONCENTRATIONS IN HUMAN HAIR

D. I. Hammer, M.D., J. F. Finklea, M.D.,
R. H. Hendricks, Ph.D., C. M. Shy, M.D.,
and R. J. N. Norton, M.D.

ENVIRONMENTAL PROTECTION AGENCY
National Environmental Research Center

BACKGROUND AND INTRODUCTION

Human scalp hair was collected to determine whether the content of three trace metals, lead (Pb), cadmium (Cd), and arsenic (As), reflected environmental concentrations in East Helena, Helena, and Bozeman, Montana. These cities represented an exposure gradient for Pb, Cd, and As as follows: East Helena > Helena > Bozeman. The explicit hypothesis to be tested was that mean hair concentrations of Pb, Cd, and As would reflect this exposure gradient and would differ significantly between cities at the $p < 0.05$ level when tested by a one-way analysis of variance. Logarithmic transformations of trace-metal data, often appropriate, were used in this study.

MATERIALS AND METHODS

The study population consisted of fourth-grade school boys who had lived in the specified city for 3 or more years. Possible confounding effects of age, sex, and hair color were controlled and the effects of dyes and hair sprays were minimized by the study design. With the cooperation of the local school boards, explanatory letters and consent forms were sent to parents of eligible children. Volunteer response was 68 percent (25 of 37) in East Helena, 54 percent (21 of 39) in Helena, and 84 percent (38 of 45) in Bozeman.

Instruction sheets for collection of hair and use of plastic vials were sent home with all volunteers. Virtually all of the samples were collected during the last 2 weeks of October 1969.

Trace-metal analyses were performed by the Western Area Occupational Health Laboratory. The samples were numbered in a random fashion and sent to the laboratory. The hair was carefully washed free of adhering materials in detergent, distilled water, alcohol, and hot EDTA (ethylenediaminotetraacetic acid). Then the hair was dried, weighed, and digested in acid prior to chemical analysis. Pb, Cd, Zn, and Cu were measured by atomic absorption spectrophotometry; arsenic was analyzed by a colorimetric method.

RESULTS

All volunteers cooperated willingly. Specimen collection was painless and required minimal inconvenience for the participants because this tissue is normally discarded periodically anyway. All data are expressed in μg/g (parts per million). Both original and log-transformed distributions for each city are presented in Tables 8-1 through 8-10. As expected, Pb, Cd, and As distributions were skewed and Zn was not. The Cu distribution, however, was skewed only for Helena and Bozeman.

Table 8-1. DISTRIBUTION OF ARITHMETIC MEAN HAIR LEAD LEVELS BY CITY

	East Helena	Helena	Bozeman
Concentration range, μg/g			
0 to 24.9	13	20	38
25 to 49.9	3	–	–
50 to 74.9	4	1	–
75 to 99.9	1	–	–
100 to 124.9	2	–	–
125 to 149.9	1	–	–
150 to 174.9	–	–	–
175 to 199	1	–	–
200 to 299	–	–	–
300 to 399	–	–	–
400 to 499	–	–	–
500 to 599	–	–	–
Statistic			
$\overline{x}$	44.3	12.1	7.6
Median	20	7.9	6.5
s	49.3	11.4	5.0
s^2	2432.92	130.9	25.0
n	25	21	38

Table 8-2. DISTRIBUTION OF ARITHMETIC MEAN HAIR CADMIUM LEVELS BY CITY

	East Helena	Helena	Bozeman
Concentration range, μg/g			
<1	10	12	25
1	4	6	10
2	5	1	1
3	4	1	1
4	1	–	–
5	–	–	–
6	1	1	–
7	–	–	–
8	–	–	–
9	–	–	–
10 to 14	–	–	–
15 to 29	–	–	–
30 to 34	–	–	–
Statistic			
$\bar{x}$	2.0	1.3	0.9
Median	1.6	0.9	0.8
s	1.54	1.30	0.58
s^2	2.39	1.70	0.34
n	25	21	37

Table 8-3. DISTRIBUTION OF ARITHMETIC MEAN HAIR ARSENIC LEVELS BY CITY

	East Helena	Helena	Bozeman
Concentration range, μg/g			
<1	2	10	27
1	2	3	1
2	1	–	–
3	2	–	–
4	4	–	–
5	1	–	–
6	–	–	–
7	1	–	–
8	2	–	–
9	–	–	–
10 to 14	–	–	–
15 to 19	–	–	–
20 to 39	1	–	–
Statistic			
$\bar{x}$	5.2	0.84	0.44
Median	4.0	0.7	0.4
s	6.0	0.33	0.27
s^2	36.2	0.11	0.07
n	16	13	28

Table 8-4. DISTRIBUTION OF ARITHMETIC MEAN HAIR ZINC LEVELS BY CITY

	East Helena	Helena	Bozeman
Concentration range, μg/g			
0 to 49	–	–	–
50 to 74	–	–	–
75 to 99	–	2	–
100 to 124	6	3	5
125 to 149	7	2	13
150 to 174	7	9	11
175 to 199	4	1	7
200 to 224	1	4	–
225 to 249	–	–	1
250 to 275	–	–	1
Statistic			
$\bar{x}$	145.2	155.4	154.2
Median	145	160	155
s	30.8	36.9	32.5
s^2	953.0	1362.2	1061.5
n	25	21	38

Table 8-5. DISTRIBUTION OF ARITHMETIC MEAN HAIR COPPER LEVELS BY CITY

	East Helena	Helena	Bozeman
Concentration range, μg/g			
≤ 10	7	9	15
11 to 20	18	10	14
21 to 30	–	1	3
31 to 40	–	1	–
41 to 50	–	–	1
51 to 60	–	–	1
61 to 70	–	–	1
71 to 80	–	–	–
81 to 90	–	–	–
91 to 100	–	–	–
101 to 110	–	–	1
≥ 111	–	–	1
Statistic			
$\bar{x}$	11.8	12.6	22.5
Median	11	11	11
s	3.0	6.0	34.7
s^2	9.3	36.45	1208.8
n	25	21	37

Table 8-6. DISTRIBUTION OF HAIR LEAD LEVELS BY CITY
($\log_e$)

	East Helena	Helena	Bozeman
Concentration range, μg/g			
0 to 0.99	–	1	4
1.0 to 1.99	7	9	19
2.0 to 2.99	6	7	14
3.0 to 3.99	3	4	1
4.0 to 4.99	8	–	–
5.0 to 5.99	1	–	–
6.0 to 6.99	–	–	–
Statistic			
$\overline{x}$	3.1	2.1	1.8
Antilog $\overline{x}$	22.3	8.9	6.1
s	1.27	0.74	0.68
s^2	1.63	0.55	0.47
n	25	21	38

Table 8-7. DISTRIBUTION OF HAIR CADMIUM LEVELS BY CITY
($\log_e$)

	East Helena	Helena	Bozeman
Concentration range, μg/g			
−1.99 to −1.0	–	–	3
−0.99 to −0.01	10	12	22
0 to 0.99	7	6	11
1.0 to 1.99	8	3	1
2.0 to 2.99	–	–	–
3.0 to 3.99	–	–	–
Statistic			
$\overline{x}$	0.41	0.04	−0.25
Antilog $\overline{x}$	1.5	1.0	0.77
s	0.78	0.67	0.60
s^2	0.62	0.45	0.36
n	25	21	37

Table 8-8. DISTRIBUTION OF HAIR ARSENIC LEVELS BY CITY

($\log_e$)

	East Helena	Helena	Bozeman
Concentration range, µg/g			
−2.99 to −2.0	1	–	5
−1.99 to −1.0	–	1	8
−0.99 to −0.01	1	9	14
0 to 0.99	3	3	1
1.0 to 1.99	7	–	–
2.0 to 2.99	3	–	–
3.0 to 3.99	1	–	–
Statistic			
$\bar{x}$	1.1	−0.34	−1.0
Antilog $\bar{x}$	3.0	0.70	0.36
s	1.2	0.46	0.71
s^2	1.6	0.21	0.50
n	16	13	28

Table 8-9. DISTRIBUTION OF HAIR ZINC LEVELS BY CITY

($\log_e$)

	East Helena	Helena	Bozeman
Concentration range, µg/g			
4.0 to 4.9	13	7	18
5.0 to 5.9	12	14	20
Statistic			
$\bar{x}$	4.9	5.0	5.0
Antilog $\bar{x}$	141.9	149.9	149.9
s	0.22	0.25	0.20
s^2	0.04	0.06	0.04
n	25	21	38

Table 8-10. DISTRIBUTION OF HAIR COPPER LEVELS BY CITY

($\log_e$)

	East Helena	Helena	Bozeman
Concentration range, μg/g			
1.0 to 1.99	1	2	1
2.0 to 2.99	24	17	28
3.0 to 3.99	–	2	5
4.0 to 4.99	–	–	2
5.0 to 5.99	–	–	1
Statistic			
$\bar{x}$	2.3	2.4	2.6
Antilog $\bar{x}$	10.4	11.5	14.4
s	0.54	0.40	0.76
s^2	0.30	0.16	0.57
n	25	21	37

A summary of hair trace-metal mean concentrations among cities is shown in Table 8-11. Pb, Cd, and As means were highest in the most polluted community, East Helena; were intermediate in Helena; and were lowest in the least polluted community, Bozeman. These differences for each pollutant were tested by a one-way analysis of variance on the original and on log-transformed data. A summary of the F ratios and their respective probabilities are shown in Table 8-12. Thus, the means for Pb, Cd, and As rank according to the hypothesis and the differences among them are significant. Moreover, the differences among the respective means for Zn and Cu, as postulated, are not significant.

Table 8-11. SUMMARY OF ARITHMETIC MEAN CONCENTRATIONS OF TRACE METALS IN EAST HELENA, HELENA, AND BOZEMAN, MONTANA

(ppm)

Metal	East Helena	Helena	Bozeman
Pb	43.1	12.1	7.6
Cd	2.0	1.3	0.9
As	5.2	0.84	0.41
Zn	145.2	155.4	154.2
Cu	11.8	15.1	22.5

Table 8-12. F RATIOS[a] OF TRACE-METAL CONCENTRATIONS IN EAST HELENA, HELENA, AND BOZEMAN, MONTANA

Arithmetic mean			Log_e		
Metal	F ratio	Probability	Metal	F ratio	Probability
Pb	14.32	$p < 0.005$	Pb	15.14	$p < 0.005$
Cd	4.98	$0.01 > p > 0.005$	Cd	7.93	$p < 0.005$
As	12.96	$p < 0.005$	As	30.27	$p < 0.005$
Zn	0.72	$0.5 > p > 0.25$	Zn	0.68	$0.5 > p > 0.25$
Cu	1.53	$0.25 > p > 0.10$	Cu	1.77	$0.25 > p > 0.10$

[a] One-way analysis of variance.

DISCUSSION

Determinations of trace metals in hair measure exogenous and endogenous deposition. The former reflects metal resulting from external contamination by substances such as dyes, shampoos, hair tonics, sweat, and dust; the latter reflects metal deposited in hair directly or indirectly through the blood stream. For example, in cities with relatively high levels of Pb in the ambient air, external contamination of the hair probably occurs. The pre-analysis hair wash included detergent and EDTA, both of which are known to remove large amounts of the metals analyzed. Thus, most or all of the superficially bound trace metals were removed from the hair before analysis. Not unreasonably, the mean levels of Cu, Zn, and Cd in all cities and Pb and As in Bozeman and Helena are lower than indicated in previously published studies in which hair was washed only with distilled water, which removed less exogenous contamination. We do not know how long it takes for a metal placed on the hair – lead dust, for example – to attach to the hair chemically; nor do we know the exact nature and extent of this bonding.

In addition, we do not know how well hair levels reflect the body burden of a metal. In humans, however, As can be found in the hair root several hours after feeding, and in rats, Cd concentrations in hair are proportional to the Cd in the diet. Comparable studies are not yet available for Pb. The extent to which hair levels of these metals correlate with teeth and bone levels has not been determined.

If these elevated levels do reflect an increased body burden (or at least increased absorption), the relative contributions of gastrointestinal and respiratory absorption routes are not known. The bulk of Pb intake is dietary, but a higher proportion of respired than ingested Pb is absorbed. Absorption by each route is affected by many factors and this study could not clarify their respective roles. This problem should be given further consideration, however.

Finally, a substantial portion of the levels of hair Pb observed in this study were as high as those found elsewhere in conjunction with illness. In other studies, the children were all much younger and often symptomatic. Also, the range of hair lead levels in all studies is quite large. Thus it is not likely that these hair levels represent Pb intoxication in these children.

To clarify further the possible relationship between hair trace-metal content and metal intoxication, it will be necessary to:

1. Repeat and extend the present study by obtaining simultaneously hair, blood, and urine samples from these children.
2. Extend and expand similar trace-metal-burden studies to include both sexes, different age groups, and other geographic areas.

SUMMARY

Parents of fourth-grade male children living in East Helena, Helena, and Bozeman were asked to volunteer for a study that involved saving the clippings of their son's next haircut. Cooperation rates were 68, 54, and 84 percent, respectively, in the three cities.

These three cities represent the following gradient for Pb, Cd, and As pollution: East Helena > Helena > Bozeman.

Hair samples were washed and analyzed for Pb, Cd, As, Zn, and Cu. The mean hair levels of Pb, Cd, and As differed among the three cities in the following order: East Helena > Helena > Bozeman. Zn and Cu levels did not differ.

REFERENCES FOR CHAPTER 8

1. Hammer, D.I. et al. Hair Trace Metal Levels and Environmental Exposure. Amer. J. Epid. *93*(2): 84-92, 1971.
2. Finklea, J.F. et al. Human Pollutant Burdens. American Chemical Society Symposium on Air Quality, April 1, 1971, Los Angeles (in press).
3. Hammer, D.I. et al. Trace Metals in Human Hair as a Simple Epidemiologic Monitor of Environmental Exposure. 5th Annual Conference on Trace Substances in Environmental Health, June 29, 1971, Columbia, Mo. (to be published).
4. Engel, R.E. et al. Environmental Lead and Public Health, EPA, APCO, Publication No. AP-90. Research Triangle Park, N.C. March 1971.
5. Forslev, A.W. "Nondestructive" Neutron Activation Analysis of Hair. J. of Forensic Sciences *11*:217-232, April 1966.

6. Jacobziner, H. Lead Poisoning in Childhood: Epidemiology, Manifestations and Prevention. Clin. Pediat. *5*:277-286, May 1966.

7. Kehoe, R.A. The Harben Lectures, 1960: The Metabolism of Lead in Man in Health and Disease. J. Roy. Inst. of Pub. Health & Hygiene, 1961.

8. Kopito, L., A.M. Briley, and H. Schwachman. Chronic Plumbism in Children. JAMA *209*:243-248, July 14, 1969.

9. Kopito, L., R.K. Byers, and H. Schwachman. Lead in Hair of Children with Chronic Lead Poisoning. New Eng. J. Med. *276*:949-953, April 1967.

10. Lee, R.E., Jr., R.K. Patterson, and J. Wagman. Particle-Size Distribution of Metal Components in Urban Air. Environ. Sci. & Tech. *2*:288-290, April 1968.

11. Neal, P.A. et al. A Study of the Effect of Lead Arsenate Exposure on Orchardists and Consumers of Sprayed Fruit. Public Health Bulletin No. 267, U.S. Government Printing Office. Washington, D.C. 1941.

12. Perkons, A.K. and R.E. Jervis. Application of Radio-Activation Analysis in Forensic Investigations. J. of Forensic Sciences *7*:449-464, October 1962.

13. Perkons, A.K. and R.E. Jervis. Trace Elements in Human Head Hair. J. of Forensic Sciences *11*:50-63, January 1966.

14. Schroeder, H.A. and A.P. Nason. Trace Metals in Human Hair. J. Invest. Derm. *53*:71-78, July 1969.

15. Shapiro, H.A. Arsenic Content of Human Hair and Nails, Its Interpretation. J. of Forensic Medicine *14*:65-71, April-June 1967.

9. POSSIBLE HAZARDS ASSOCIATED WITH INGESTION OF GARDEN VEGETABLES CONTAMINATED BY TRACE METALS

Samuel I. Shibko, Ph.D.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Food and Drug Administration

INTRODUCTION

Contamination of garden vegetables in the Helena Valley, Montana, area by certain trace metals – arsenic, cadmium, lead, and zinc – known to be emitted by industries in the area constitutes a potential hazard to human health. In order to assess the adverse effects that could possibly be associated with the inclusion in the human diet of vegetables grown in the Valley, concentrations of the specified trace metals in the vegetables and the daily consumption of these vegetables must first be determined. In addition, the acceptable daily intake of arsenic (As), cadmium (Cd), lead (Pb), and zinc (Zn) must be estimated. The estimates of acceptable dietary intake given in this paper have not been derived from definitive toxicological data but from data on the trace-metal content of foodstuffs, air, and water, and from data on the rates and routes of excretion of trace metals.

ZINC METABOLISM

Balance

Human zinc balance data, taken from a study by Schroeder et al.,[1] are summarized in Table 9-1. Zinc absorption and excretion are controlled homeostatically. In the mouse, for example, zinc homeostasis is maintained by two

Table 9-1. ESTIMATED ZINC BALANCE IN MAN[1]

Source	Zn intake, mg/day	Excretion route	Zn output, mg/day
Food	12.0	Urine	0.5
Water	0.5	Feces	10.6
Air	0.1	Sweat	0.5
		Other	1.0
Total	12.6		12.6

9. POSSIBLE HAZARDS ASSOCIATED WITH INGESTION OF GARDEN VEGETABLES CONTAMINATED BY TRACE METALS

Samuel I. Shibko, Ph.D.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Food and Drug Administration

INTRODUCTION

Contamination of garden vegetables in the Helena Valley, Montana, area by certain trace metals – arsenic, cadmium, lead, and zinc – known to be emitted by industries in the area constitutes a potential hazard to human health. In order to assess the adverse effects that could possibly be associated with the inclusion in the human diet of vegetables grown in the Valley, concentrations of the specified trace metals in the vegetables and the daily consumption of these vegetables must first be determined. In addition, the acceptable daily intake of arsenic (As), cadmium (Cd), lead (Pb), and zinc (Zn) must be estimated. The estimates of acceptable dietary intake given in this paper have not been derived from definitive toxicological data but from data on the trace-metal content of foodstuffs, air, and water, and from data on the rates and routes of excretion of trace metals.

ZINC METABOLISM

Balance

Human zinc balance data, taken from a study by Schroeder et al.,[1] are summarized in Table 9-1. Zinc absorption and excretion are controlled homeostatically. In the mouse, for example, zinc homeostasis is maintained by two

Table 9-1. ESTIMATED ZINC BALANCE IN MAN[1]

Source	Zn intake, mg/day	Excretion route	Zn output, mg/day
Food	12.0	Urine	0.5
Water	0.5	Feces	10.6
Air	0.1	Sweat	0.5
		Other	1.0
Total	12.6		12.6

mechanisms that are localized in the liver, pancreas, and gastrointestinal tract.[2] Zinc absorption is influenced not only by homeostatic mechanisms but by food constituents as well, notably phytic acid. Calcium intake, however, does not appear to reduce zinc absorption.[3]

Toxicity

Zinc compounds are relatively nontoxic, although acute episodes of toxicity have been reported. Few studies are available, however, by which to judge the long-term effects of orally administered zinc. In one study, the administration of $ZnSO_4$ (660 mg/day) for up to 22 months, to observe its effects on wound healing, failed to produce any adverse effects.[4] Furthermore, exposure of man to inhalation of metallic zinc, zinc oxide, and zinc sulfide for long periods produced no adverse effects.[5] The biological half-life of zinc in man is 315 days.

CADMIUM METABOLISM

Balance

No information is available on the biological half-life of cadmium or on mechanisms of cadmium absorption and execretion in the human, except that a homeostatic mechanism for control of cadmium in man does not appear to exist. Cadmium absorption from dietary intake is low. Absorption, metabolism, and physiological effects of cadmium may be markedly influenced by other dietary components. For example, experimental studies with laboratory animals have shown that zinc, iron, copper, selenium, calcium, sulfhydryl compounds, and vitamins D and C are important in this respect. Some information on the typical daily intake of cadmium and on its excretion has been estimated by Schroeder et al.[1] and is shown in Table 9-2.

Table 9-2. ESTIMATED CADMIUM BALANCE IN MAN[1]

Source	Cd intake, μg/day	Excretion, route	Cd output, μg/day
Food	200	Urine	50
Water	15	Feces	163
Air	<1	Air	–
Total	215		213

Toxicity

Unlike zinc, cadmium is toxic to man and other mammals, and causes a number of adverse effects. In man, long-term industrial exposure to Cd results in renal tubular damage, which is characterized by proteinuria. Extreme exposure may result in osteomalacia. Studies with experimental animals indicate that subcutaneous injection of cadmium into newborn rats causes hemorrhagic disease of the central nervous system.[6] Intermittent injections of cadmium chloride into rabbits cause amyloid disease, but this disease has not been associated with long-term human exposure to cadmium. The toxic effects of cadmium in gonadal tissues have been characterized in experimental animals, but are not known in man.

In a study on the effects of chronic exposure of rats to Cd, reported by Schroeder et al.,[7,8] rats received, from time of weaning, drinking water containing 5 ppm Cd. Hypertension began to appear after about a year, and the incidence, which was greatest in females, increased with age. Both sexes had decreased median life spans compared to cadmium-free controls. In this study, the renal concentration of Cd found in the rat kidney was less than that reported for human kidney. Schroeder[9] considers one common form of hypertension in man to be related to the accumulation of cadmium in the kidney, probably in the renal cortex, where cadmium is firmly chelated to a zinc- and cadmium-containing protein.

ARSENIC METABOLISM

Balance

The estimated arsenic balance in man is given in Table 9-3, which is derived from Schroeder and Balassa.[10] The data presented in this table were calculated for arsenate, the pentavalent form of As, which is the usual form in which arsenic occurs in soil and water. From the data in Table 9-3, it is apparent that no arsenate is retained in the human body. Arsenate appears to be controlled homeostatically, and most of the arsenate that is absorbed is excreted via the kidney.

Table 9-3. ESTIMATED ARSENIC[a] BALANCE IN MAN[10]

Source	As intake µg/day	Excretion route	As output µg/day
Food	890	Urine	225
Water	10	Feces	675
Air	–	Air	–
Total	900		900

[a] Balance data calculated on assumption that all As taken is in form of arsenate.

Toxicity

Trivalent arsenic (arsenite), as opposed to arsenate, is extremely toxic. Arsenite chelates with the sulfhydryl groups of proteins and is only slowly excreted, mainly via the intestine.

LEAD METABOLISM

Balance

Two slightly different estimates of lead balance in man have been suggested, both of which are given in Table 9-4.[11,12,13]

The metabolism of lead in the human, which is complex, is not fully understood. The absorption of Pb is low and is influenced to a large degree by the composition of the diet. For example, calcium, pectin, and protein hydrolysates are known to interfere with Pb absorption.[11]

Table 9-4. ESTIMATED LEAD BALANCE IN MAN[11,12,13]

Source	Pb intake, mg/day		Excretion route	Pb output, mg/day	
	Kehoe	Monier-Williams		Kehoe	Monier-Williams
Food	0.22	0.31	Feces	0.30	0.32
Water	0.10	0.02	Urine	0.05	0.03
Air	0.08	0.02	Stored in bones	0.05	–
Total	0.40	0.35		0.40	0.35

Following absorption, lead is distributed throughout the body, the highest concentrations appearing in red blood cells, kidney, liver, and bone. Lead is excreted via urine and feces.[13]

Toxicity

Kehoe considers the maximum allowable intake of lead to be 0.6 milligram per day; ingestion of twice that amount is injurious after 10 years or more.[14] Severe Pb poisoning causes a variety of effects, including anemia, neurological disorders, and deranged porphyrin metabolism. As opposed to clinical stages of lead poisoning, the symptoms of which are well known, subclinical lead poisoning is not yet well characterized.

The effects of chronic exposure of rats to lead were studied by Schroeder et al., who gave rats 5 ppm lead in drinking water from weaning until death. Lead exerted a continuous adverse effect at all ages and in both sexes, as evidenced by reduced life spans and increased mortality rates. Concentrations of lead in the rat organs were similar to those reported for man.[7]

DAILY CONSUMPTION OF GARDEN VEGETABLES AND FRUITS

In the absence of definite information on the dietary habits of residents of the Helena Valley area, the probable daily consumption of certain garden vegetables and fruits was estimated from data reported by Ter Haar,[15] which were acquired through a U.S. Department of Agriculture food-consumption survey. The values given in Table 9-5 were estimated to the nearest 0.1 percent from the USDA data, except for the values for kohlrabi and rutabaga, which were arbitrarily determined.

Table 9-5. ESTIMATED DAILY CONSUMPTION OF GARDEN VEGETABLES AND FRUITS[15]

Vegetable or fruit	% of diet	Consumption, g/day[a]
Apples	1.81	27
Beets	0.44	6
Cabbage	0.7	10.5
Carrots	0.5	7.5
Kohlrabi	0.2	3
Lettuce	0.5	7.5
Onions	1.01	15
Potatoes	5.6	84
Rutabagas	0.2	3
String beans	1.0	15
Total	11.96	178.5

[a] Estimated daily consumption is based on 1500-g/day for a 60-kg (132-lb) person.

ESTIMATED DIETARY LEVELS OF ARSENIC, CADMIUM, LEAD, AND ZINC

The levels of dietary trace metals were estimated from the maximum values reported by Hindawi and Neely (Chapter 5, Table 5-3). No correction was made for contributions to trace-metal levels from dust or soil adhering to the unwashed vegetables, although it is recognized that adhering materials could have contributed considerably to the levels observed, particularly in the case of leafy vegetables. As seen in Table 9-5, the vegetables for which values are given constitute only 11.96 percent of food consumed daily. The assumption has been made that the remaining 88.04 percent of the diet will contain As, Cd, Pb, and Zn at concentrations approximating those reported by Schroeder for foodstuffs.[1,10,13]

Although the diet represents the major source of As, Cd, Pb, and Zn, the daily intake from air must be estimated because these elements are present not only in soil and water but in the atmosphere as well. Contributions to metal intake from the air were calcualted by using a factor derived from lead data reported by Harley,[16] in which the total annual intake by man of lead from the air was calculated to be 15 milligrams if the average concentration of atmospheric lead were 2 micrograms per cubic meter of air. Applying the same ratio (of metal present in the atmosphere to that inhaled) to the upper levels of As, Cd, Pb, and Zn that can occur in particulate matter, the daily intake of each of the metals was obtained: As, 60 μg; Cd, 60 μg; Pb, 80 μg; and Zn, 60 μg. Schroeder's estimate of the daily intake of these elements from air is: As, 2 μg; Cd, 1 μg; Pb, 20 to 80 μg; and Zn, 100 μg.[1,10,13]

The higher arsenic intake derived by means of Harley's factor, as opposed to Schroeder's estimate, does not represent a significant difference in the total daily intake; however, the difference in cadmium intake values represents a 25-percent increase in total daily cadmium intake. An estimate of the total daily intake of As from food, water, and air is given in Table 9-6.

Table 9-6. ESTIMATED TOTAL DAILY INTAKE OF ARSENIC, CADMIUM, LEAD, AND ZINC FROM DIET, WATER, AND AIR

Metal	Estimated intake in uncontaminated areas,[a] μg/day	Estimated intake in East Helena area,[b] μg/day
Arsenic	900	1,016 (112%)
Cadmium	215	322.8 (150%)
Lead	400	855 (212%)
	350	853 (247%)
Zinc	12,000	13,420 (112%)

[a] Estimated values given in Tables 9-1 through 9-4.

[b] Sum of values calculated for total dietary intake (Table 9-7), intake via inhalation, and water (Tables 9-1 through 9-4). Figures in parentheses represent estimated total daily intake in East Helena area, expressed as percentage of estimated total daily intake in uncontaminated area.

SIGNIFICANCE OF DATA

In an attempt to estimate the possible hazards associated with the inclusion in the human diet of garden vegetables grown in the Helena Valley area, the contribution of these vegetables to the daily intake of As, Cd, Pb, and Zn has been estimated and is shown in Table 9-7. In all cases, the maximum values possible have been utilized in the calculations; that is, all vegetables in the diet were assumed to have been grown in the area and were assumed to contain the maximum concentrations of metals reported by Hindawi and Neely (Table 5-3). In spite of the bias introduced by these assumptions, significant increases in dietary intake of trace metals as the result of vegetable consumption were seen only for cadmium and lead (based on balance levels reported in Schroeder et al.[1]). Daily lead intake from vegetables in the Helena Valley area is estimated to be double the amount reported by Schroeder et al. as balance intake (Table 9-4). Daily cadmium intake is 30 percent higher than reported balance intake[1](Table 9-2).

The best indication of the significance of the high lead intake estimated to occur in the Valley is the statement by Kehoe that the maximum allowable daily

Table 9-7. ESTIMATED DAILY INTAKE OF ARSENIC, CADMIUM, LEAD, AND ZINC FROM THE DIET

Metal	Intake[a] from garden vegetables and fruit, μg	Intake[b] from rest of diet, μg	Total dietary intake,[c] μg
Arsenic	164	782	946 (106%)
Cadmium	82.8	175	257.8 (129%)
Lead	481	194	675 (304%)
		272	753 (248%)
Zinc	2,260	10,600	12,860 (108%)

[a] Calculated on basis of data in Table 5-3 and Table 9-5.

[b] Based on assumption that approximately 88% of diet will contain As, Cd, Pb, and Zn at concentrations approximating those reported in Tables 9-1 through 9-4.

[c] Figures in parentheses are percentages of daily intake (from diet) reported in Tables 9-1 through 9-4.

intake of lead is 0.6 mg and that twice that amount, 1.2 mg/day, is injurious over a period of 10 years or more.[14] Although lead intake by residents of the Helena Valley area exceeds 0.6 mg/day (from diet and air), intake is still well below 1.2 mg/day (Table 9-6). Nonetheless, Kehoe's data were from a small number of healthy individuals and were not necessarily representative of the problem that exists in the Helena Valley. Thus, it would be inadvisable to consider intake of lead at levels between 0.6 and 1.2 mg/day as being totally without hazard. It is unlikely, however, that the actual levels of Pb in the diet would be as high as those given in Table 9-6 and in Table 5-3, because (1) data given in these tables were obtained on unwashed vegetables and (2) valley-grown garden vegetables would probably not be the entire source of vegetables on a continuous basis. On the other hand, the intake from dietary lead will greatly exceed these figures on occasion, because dietary patterns vary. For example, consumption of large amounts of lettuce, which appears to be a lead accumulator, would greatly increase the lead intake. Such increased consumption will probably be sporadic, however, so that the potential for danger will be minimized.

In the case of cadmium, the dietary intake suggested by Schroeder et al.[1] is exceeded by approximately 30 percent, and the amount derived from air may contribute an additional 25 percent (Tables 9-6 and 9-7). However, since exposure via inhalation results in absorption of cadmium that exceeds absorption from the diet, the increased cadmium in air may present a greater problem than that associated with the diet. No information is available on the significance of this increase, although it may result in increased deposition of cadmium in the kidneys. The various exaggerated factors that have been considered for lead also apply to cadmium, and it is likely, therefore, that the actual intake will be somewhat lower and that less cadmium will be ingested, absorbed, and concentrated in the tissues. More recent publications suggest that the total dietary intake of cadmium in uncontaminated areas is 50 μg/day.[17] The estimates of cadmium intake in the contaminated area show a considerable increase over this value. The general conclusions relating to the possible effects remain unchanged.

Because limited data are available, it has not been possible to determine whether consumption of meat or milk produced in the area will appreciably alter the human body burden of cadmium and lead. Available data on animals in the area indicate that the Pb and Cd in beef liver muscle, milk, chicken and rabbit muscle, and swine heart and sausage are of the same order of magnitude as those observed for edible meats and organs by Schroeder et al.[1,13] and for milk by Murthy and Rhea.[18] The high Cd values observed for horse kidney and liver may be the result of grazing habits of horses. Additional analyses of organs and tissues of beef cattle raised in this area would be of value in determining whether their inclusion in the diet is potentially hazardous.

Although no immediate, acute hazards appear to be associated with consumption of trace-metal-contaminated vegetables grown in the Helena Valley area, little is known about the effects of continuous exposure (from diet and from air) to low concentrations of Cd and Pb. Because it is likely that levels of intake will exceed those of elimination, tissue accumulation of these elements is to be expected. Although unavailable at the present, data on trace-element content of tissues from people who have spent most of their lives in this area would be useful in determing effects of chronic exposure. It is not known whether these individuals will develop a degree of tolerance to the increased intake of these trace metals, or if accumulation of these metals will eventually result in physiological changes.

SUMMARY

1. All calculations, estimations, and conclusions are based on assumptions rather than on toxicological facts. These estimates were made because of the unusual situation that exists in the Helena Valley area. Extensive toxicological studies will be required before definite opinions can be given regarding the effects on man of chronic exposure to low levels of As, Cd, Pb, and Zn.
2. Calculation of the estimated daily dietary intake of these metals from garden vegetables containing the maximum levels of the metals indicates that the body burden of these metals suggests by Schroeder et al.[1,10,13] and Kehoe[14] will be exceeded for lead and cadmium.
3. These calculations do not take into account the fact that the vegetables were not washed before analysis, or that garden vegetables may only provide a fraction of the total dietary intake of vegetables, or that the inhabitants of the area may have special dietary habits.

4. Based on these calculations, the daily intake of lead from garden-grown vegetables would be 0.48 mg. The daily intake of lead from all food could be as high as 0.753 mg. The total daily intake of lead, including that from water and air, could be as high as 0.95 mg. The second and third figures exceed the upper limit suggested by Kehoe.[14] Kehoe believes that no major hazard is associated with this level except in the case of continuous intake for many years; it is significant, then, that the problem in the Helena Valley area is one of chronic ingestion of lead.

5. The significance of the increased cadmium intake – approximately 55 percent over the acceptable body burden, 30 percent of which comes from diet and 25 percent from air – is not known. The factors indicated in (3) above may minimize any possible hazard.

6. Inasmuch as these results apply to relatively few sections of the Helena Valley area – namely those in which the concentrations of trace elements are the highest reported – it would appear that, in general, the "normal" consumption of garden vegetables in the area is safe.

7. It should be understood that conclusion (6) does not take into account abnormal dietary patterns and high-risk populations; it does consider distribution of trace-metal residues to be fairly constant year by year.

8. Additional data are required to determine whether a hazard exists from the consumption of milk and meat derived from cattle in the area.

9. For a more complete analysis of the problem, future studies should include a survey of the dietary habits of the inhabitants of the area, with particular inquiry into their preparation and consumption of garden vegetables.

10. These conclusions apply only to this specific problem and should not be construed as a general statement relating to the safety of consuming foods containing these trace elements.

REFERENCES FOR CHAPTER 9

1. Schroeder, H. A. et al. Essential trace metals in man: Zinc. Relation to environmental cadmium. J. Chron. Dis. *20*:169-210, 1967.

2. Cotzias, G. C., D. C. Berg, and B. Selleck. Specificity of zinc pathway through the body: Turnover of ^{65}Zn in the mouse. Amer. J. Physiol. *202*:359-363, 1962.

3. Spencer, H. et al. Studies of ^{65}Zn Metabolism in Man. In: A.S. Prasad (ed.), *Zinc Metabolism.* Springfield, Ill. C. C. Thomas. 1966. pp. 339-362.

4. Pories, W. J. et al. Acceleration of Wound Healing in Man with Zinc Sulfate Given by Mouth. Lancet *1*, 121, 1967.

5. Batcheler, R. P. et al. Clincial and Laboratory Investigation of the Effect of Metallic Zinc, of Zinc Oxide and of Zinc Sulfide upon the Health of Workmen. Ind. Hyg. *8* :322-363, 1926.

6. Gabbiani, G., C. Baic, and C. Deziel. Toxicity of Cadmium in the Central Nervous System. Exp. Neurology *18*:154-160, 1967.

7. Schroeder, H. A., W. H. Vinton, Jr., and J. J. Balassa. Effect of Chromium, Cadmium and Lead on the Growth and Survival of Rats. J. Nutrition *80*:48-54, 1963.

8. Schroeder, H. A., J. J. Balassa, and W. H. Vinton, Jr. Chromium, Cadmium and Lead in Rats: Effects on Life Span, Tumors and Tissue Levels. J. Nutrition *86*:51-66, 1965.

9. Schroeder, H. A. Cadmium, Chromium and Cardiovascular Disease. Circulation *35*:570-582, 1967.

10. Schroeder, H. A. and J. J. Balassa. Abnormal Trace Metals in Man: Arsenic. J. Chron. Dis. *19*:85-106, 1966.

11. Monier-Williams, G. W. Trace Elements in Food. New York, New York. John Wiley & Sons, Inc. 1949. p. 68,72.

12. Kehoe, R. A. PHS Aspects of Increasing Tetraethyl Lead Content in Motor Fuel. U.S. DHEW, Public Health Service. PHS Publication No. 712. Washington, D. C. 1959.

13. Schroeder, H. A. and J. J. Balassa. Abnormal Trace Metals in Man: Lead. J. Chron. Dis. *14*:408-425, 1961.

14. Kehoe, R. A. The Metabolism of Lead in Man in Health and Disease. Arch. Environ. Health *2*:418-422, 1961.

15. Ter Haar, G. Air as a Source of Lead in Edible Plants. Environ. Sci. & Tech. *4*:226-229, 1970.

16. Harley, J. Sources of Lead in Perennial Rye Grass and Radishes. Environ. Sci. & Tech. *4*:225, 1970.

17. Frigberg, L., M. Piscator, and G. F. Norberg. Cadmium in the Environment. Cleveland, Ohio. The Chemical Rubber Company. 1971.

18. Murthy, G. K. and U. Rhea. Cadmium and Silver Content of Market Milk. J. Dairy Sci. *51*(4):610-613, 1968.

10. POLLUTION SOURCES

Francis M. Alpiser, Marius J. Gedgaudas,
and Harold B. Coughlin

ENVIRONMENTAL PROTECTION AGENCY
Office of Air Programs

INTRODUCTION

Emission Summary for Helena Valley

An emission inventory covering sulfur oxides, particulate matter, nitrogen oxides, hydrocarbons, and carbon monoxide was made for the Helena Valley area in 1968. Although industrial processes are the primary source of emissions in the Valley, fuel combustion in stationary sources, transportation, and open burning also contribute to the overall problem.

The primary pollutant is sulfur dioxide, of which approximately 71,100 tons is emitted annually, based on operations at the time of the study. Particulate emissions, totaling nearly 8300 tons, are lower than the actual amount, because dust from unpaved roads is a major problem in the area; no accurate method is available for estimating such emissions, however. Carbon monoxide emissions amounted to approximately 22,000 tons, and nitrogen oxides and hydrocarbons totaled approximately 2600 tons and 2100 tons, respectively.

Table 10-1 summarizes the pollutants in percent for the four source categories.

Table 10-1. 1968 EMISSIONS IN HELENA VALLEY, MONTANA, AREA
(%)

Source category	Pollutants				
	SO_2	NO_2	Particulates	HC	CO
Industrial processes	98.6	Negligible	70.4	1.2	3.4
Fuel combustion	1.3	53.0	25.7	Negligible	0.2
Transportation	0.1	43.9	2.5	88.5	93.5
Solid waste disposal	Negligible	3.1	1.4	10.3	2.9
Total	100.0	100.0	100.0	100.0	100.0

East Helena Industrial Complex

The complex consists of the lead smelter of American Smelting and Refining Company (ASARCO), the slag-processing activities of the Anaconda Company, and the paint pigment production of the American Chemet Corporation.

ASARCO contributes nearly 70,500 tons of sulfur oxides, or 99 percent of the area total. This figure is based on the operations of ASARCO during the period covered by this report. The plant, as presently operating, emits approximately 120,500 tons of SO_2 per year, with a potential yearly discharge of approximately 138,000 tons if operated at full smelting capacity. Particulate emissions are 5800 tons per year, the majority of which is emitted by the Anaconda Company and ASARCO; other emissions are contributed by periodic gravel crushing, asphalt batching, and stockpile blowing.

Table 10-2 lists the operations of the three contributors and the sulfur oxide and particulate emissions for each.

LEAD SMELTING–
AMERICAN SMELTING AND REFINING COMPANY

Process Description

The American Smelting and Refining Company operates a custom lead smelter at East Helena. The plant was built in 1885 and was acquired by ASARCO in 1899. Figure 10-1 is a simplified flow diagram for the lead plant.

A custom smelter is a plant with flexibility to process ore concentrates from both domestic and foreign mines. Ore concentrate is made by upgrading ore to 50 to 70 percent lead using differential flotation. The time for processing a definite concentrate varies from 3 months to 1 year or more, depending on the amount purchased.

Concentrates now being processed have a sulfur content greater than 30 percent. They are from the Kidd Creek Mine operated by Texas Gulf Sulfur Company at Ontario, Canada. Domestic concentrates of lead ore used previously had 10 to 20 percent sulfur. A return to domestic concentrates is not likely because ASARCO is comitted to using the Canadian concentrate.

Raw Materials

Various shipments of lead concentrates are sampled to determine the metal and sulfur contents. The concentrates, after being mixed thoroughly with zinc residues, limestone, and siliceous ore, are then pelletized to give a charge conforming to metallurgical requirements. The charge is delivered by belt conveyor to the sintering plant.

Table 10-2. EMISSIONS FROM EAST HELENA INDUSTRIAL COMPLEX

(tons/day)

		Emissions					
		SO_2 production			Particulates production		
Company	Operation	Reduced	Normal	Maximum	Reduced	Normal	Maximum
ASARCO	Sintering	184.6	315.6	355.1	0.3	0.5	0.5+
	Smelting	8.4	14.6	23.2	Negligible	Negligible	Negligible
	Miscellaneous	Negligible	Negligible	Negligible	a	a	a
Subtotal		193.0	330.2	378.3	0.3	0.5	0.5+
Anaconda	Fuming	13.0	13.0	13.0	b	b	b
	Miscellaneous	c	c	c	1.0	1.0	1.0
Subtotal		13.0	13.0	13.0	1.0	1.0	1.0
American Chemet	Pigment production	Negligible	Negligible	Negligible	d	d	d
Total		206.0	343.2	391.3	1.3	1.5	1.5+

[a] The outside storage of concentrates contributes a significant but undetermined amount of particulates.
[b] Emissions also occur during the slag charging and at the coal mill, but no estimates have been made.
[c] Emissions occur when slag is dumped, but no estimate of their quantity has been made.
[d] Emissions are controlled by cyclones and bag filters with high collection efficiencies.

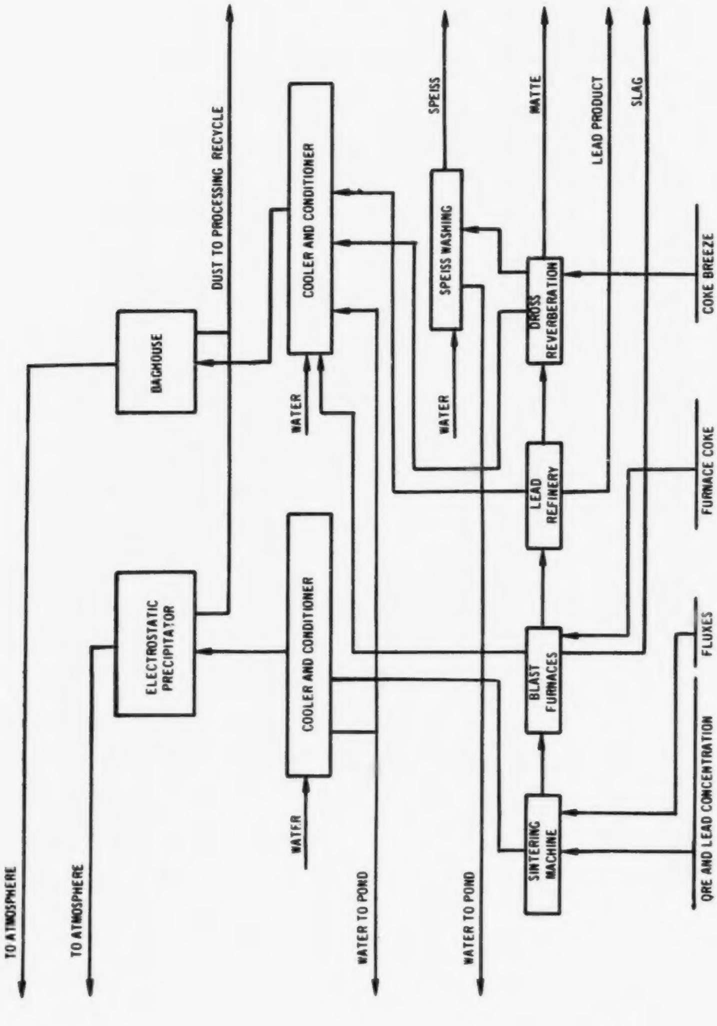

TO ATMOSPHERE
TO ATMOSPHERE
WATER TO POND
WATER TO POND
ELECTROSTATIC PRECIPITATOR
BAGHOUSE
DUST TO PROCESSING RECYCLE
COOLER AND CONDITIONER
COOLER AND CONDITIONER
WATER
WATER
WATER
SPEISS WASHING
SPEISS
MATTE
LEAD PRODUCT
SLAG
SINTERING MACHINE
BLAST FURNACES
LEAD REFINERY
DROSS REVERBERATION
ORE AND LEAD CONCENTRATION
FLUXES
FURNACE COKE
COKE BREEZE

Figure 10-1. Simplified flow diagram for lead plant.

Sintering

The charge is mixed with return sinter and fed to one of four Dwight Lloyd sintering machines where the sulfur content is reduced through oxidation or roasting and the charge is agglomerated into a product known as "sinter." The sinter is screened to remove fines, and the coarse fraction is delivered to the blast furnace. The fines are crushed and returned for blending with fresh charge from the charge-preparation system. The gases from the sintering machies are conducted through flues to an electrostatic precipitator, where most of the dust in the gases is removed. The cleaned gases, containing about 2.0 percent SO_2 and some metallic dust, are discharged to the atmosphere through a 400-foot stack.

Blast Furnace Charge

Finished sinter, together with coke, is charged to one of two blast furnaces where it is melted and reacted to form lead bullion and slag, with oxygen-enriched air being used to aid the reaction. The molten products flow from the furnace continuously through a patented tapper and are separated by gravity in a brick-lined settler. The slag overflows the settler into slag pots for delivery to Anaconda's zinc fuming plant. The lead bullion is tapped into pots for transfer to the drossing plant. Offgas from the blast furnace passes through a baghouse prior to discharge to the atmosphere through three stacks.

Lead Refining

Molten lead bullion is transported by rail to the drossing plant where it is poured into one of several large kettles and allowed to cool. Molten bullion contains basically lead, plus significant amounts of dissolved gold, silver, copper, arsenic, and antimony. As the bullion cools, many of the impurities separate out as dross, which is skimmed off and mixed with soda ash and coke breeze before being charged to the dross reverberatory furnace. This furnace produces lead bullion, lead-copper matte, a slag composed mainly of metal sulfides, and copper speiss, which is metal arsenides and antimonides. The molten bullion is recycled to the cooling kettles, while the matte and speiss are shipped to another plant out of the area for copper recovery. The gases from the dross reverberatory furnace are mixed with blast furnace offgases and sent to the baghouse. The gas, which contains less than 0.2 percent SO_2 and traces of metallic dust, is discharged to the atmosphere through three 117-foot stacks.

After dross removal, the bullion is further purified by the addition of sulfur and by cooling, which result in a copper sulfide matte that is skimmed off. The matte is shipped to another plant for recovery, and the purified bullion is cast into large blocks for delivery to a lead refinery in another state. At this facility the precious metals and other impurities are removed and the lead is cast into ingots for marketing.

Emissions

The smelter emits a large amount of sulfur dioxide and a significant amount of dust. The pollutants are emitted to the atmosphere through stacks at the electrostatic precipitator and the baghouse, with the emission rates varying depending on the charge rate to the sintering plant and the blast furnaces.

Prior to the summer of 1969, both blast furnaces were operated, with a total charge of 1200 tons per day. During the period of air quality monitoring conducted in conjunction with this study, only one furnace was in operation at a rated capacity of 700 tons per day. In the fall of 1969, one altered furnace with a capacity of 1200 tons per day was placed in operation and the 700-ton-per-day furnace was idled and placed in a standby status. The sintering plant has a maximum daily capacity of 1350 tons; this has been reduced, however, to balance the feed requirements of the 1200-ton-per-day blast furnace. Unless provisions are made for the intermediate storage of sinter, it does not appear that the blast furnaces will again be operated simultaneously.

Sulfur Dioxide

During the period of reduced blast furnace operation, it is estimated that 193 tons of SO_2 per day was emitted to the atmosphere from sintering operations and from the furnace. During normal operations, 1200 tons per day will be charged to the sintering plant and to the enlarged blast furnace; this charge will result in 330 tons of SO_2 per day being discharged to the atmosphere. If both furnaces were operated simultaneously at a rated capacity of 1900 tons per day, 379 tons of SO_2 per day would be discharged.

The above estimates are based on information supplied by ASARCO management; those data indicate that the sintering charge contains 12 to 14 percent lead and about 14.8 percent sulfur. About 89 percent of the sulfur in the charge stock is emitted as SO_2 during the sintering operation. Of the remaining 11 percent, a portion is emitted as SO_2 from the blast furnace, with only an insignificant amount being emitted from the reverberatory furnace. The sulfur not emitted as SO_2 remains in the slag, which is sent to the Anaconda plant for zinc recovery. The offgas from the sintering operation passes through an electrostatic precipitator for dust removal and is discharged to the atmosphere. The offgases from the blast and reverberatory furnaces are combined and pass through a baghouse prior to discharge to the atmosphere.

Particulates

Dust from the sintering operation passes through the electrostatic precipitator prior to discharge to the atmosphere. During the time the sintering plant was operating at a reduced rate, it is estimated that 560 pounds per day of dust was being discharged to the atmosphere. This estimate is based on data provided by ASARCO that the precipitator has an efficiency of 97 percent and that, when sintering at a rate of 1000 tons per day, 800 pounds per day of dust is emitted. At the normal sintering rate of 1200 tons per day, it is estimated that 960 pounds per day will be emitted, whereas at the maximum rate of 1350 tons per day, 1080 pounds per day will be emitted. These losses would be considerably larger if a more reasonable precipitator operating efficiency is assumed.

Plant management has reported that the baghouse serving the blast and reverberatory furnaces has an operating efficiency greater than 99 percent. With no other data available it is estimated that particulate emissions are negligible from this source.

Another source of particulate emissions results from the outside storage of concentrates. During periods of gusty winds, considerable dust with a high lead content is transported to areas adjoining the smelter. No estimate has been made of the quantity of these emissions due to lack of data, but it is felt that they may be of a significant nature.

The effluent from the precipitator and baghouse contains metals including lead, cadmium, and arsenic. These materials are considered to be in the form of particulates, but no estimate of the quantity has been made due to a lack of data.

Plant Effluent

Plant effluent consists of cooling water and wash water from the processing of speiss from the reverberatory furnaces. This water is discharged into ponds that then discharge into Prickly Pear Creek.

The cooling water is discharged at a rate of 1450 gallons per minute into retention ponds for cooling. Cooling is necessary so that the water discharged into the creek does not raise the temperature of the creek more than 24° F. Process water from the speiss operation is discharged into the ponds for a period of 1 hour per day at a rate of 600 gallons per minute.

The cooling water is essentially free of metals, but the speiss process water has high concentrations of them. Analysis by the State of Montana of the retention pond's discharge into the creek indicates the following metals and their concentrations in parts per million: arsenic, 0.8 (0.03); copper, 1.12 (0.086); lead, 0.58 (0.044); and iron, 1.10 (0.80). Concentrations indicated within parentheses were found in samples taken from the creek downstream of the plant.

Air Pollution Control

Sulfur Dioxide

American Smelting and Refining Company has made no attempt to remove or recover the SO_2 emitted during sintering and smelting operations. A 400-foot stack is used to reduce the ground-level impact near the smelter of SO_2 emissions from sintering.

Three monitoring stations are used to regulate the operation at the sintering plant. Ground-level SO_2 concentrations are recorded in the vicinity of the plant complex by the monitors that are situated approximately 1 to 1.5 miles from the stack. When any station indicates a concentration of 0.7 ppm SO_2 for 15 minutes or longer, the sintering plant is to be shut down and is not to be started up again until the station indicates an SO_2 concentration of less than 0.5 ppm for 15 minutes or longer. The time required for the reduction varies from 1 to 3 hours, but is normally less than 2 hours.

In the spring of 1970, ASARCO placed in operation an induced-draft fan and stack heater in the 400-foot sintering plant stack. These additions increased the effluent from 190,000 cfm at 140° to 325,000 cfm at 260° F in an effort to allow the stack plume to penetrate the frequent, intense inversions that occur in the East Helena area. It is estimated that this has increased the effective stack height from 533 to 743 feet when meteorological conditions are favorable. When an intense inversion of 20° to 40° F occurs, the effective stack height will be significantly lower. Intense inversions with 1000- to 1200-foot ceilings occur in the Helena Valley about two-thirds of the mornings from September through February. When an intense inversion exists, the plume will be unable to penetrate the inversion and will result in high ground-level SO_2 concentrations caused by the inadequate dilution.

Emission control techniques are presently available than can substantially reduce the SO_2 emissions from the sintering and smelting operations. The selection of a technique to control SO_2 emissions will depend upon such factors as the required degree of control and the economic, social, and political ramifications of control. Possible techniques available for control or reduction of emissions from the sources are changes in raw feed material, the production of sulfur or sulfuric acid, and effluent cleaning.

Canadian ore concentrates now used at the smelter have sulfur contents greater than 30 percent. Domestic concentrates formerly processed had sulfur contents between 10 and 20 percent. A return to domestic concentrates with 15 percent sulfur would sharply reduce SO_2 emissions from the sintering and smelting operations.

Emissions of SO_2 from the sintering operation could be greatly reduced if the SO_2 were converted to sulfuric acid or sulfur. Acid can be produced by using a contact sulfuric acid plant, which can be designed to operate on SO_2 concentrations as low as a fraction of a percent, but economic considerations indicate the SO_2 concentration should be in the range of 4 to 6 percent. It would be necessary to improve the efficiency of the sinter plant dust-cleaning equipment because the acid plant would be unable to operate at the present grain loadings.

Processes to produce sulfur from sulfur dioxide are also available and have been used in Canada and elsewhere. These processes require at least partial reduction of SO_2 to sulfur; this is normally accomplished by using natural gas. The remaining sulfur oxides and hydrogen sulfide are then catalytically converted to elemental sulfur. At the present, overall economics favor the production of acid, but the use of sulfur production processes may increase due to sulfur's ease of handling and lower transportation costs.

Scrubbing techniques are available to clean the effluent from the sintering and smelting operations. Limestone can be used on these streams with an estimated SO_2 removal efficiency of 80 percent. This type of control technique does not provide a useful sulfur by-product and, for this reason, may best be applied to streams not suited for acid- or sulfur-recovery processes.

Particulates

The control of particulate emissions from plant processes is attempted by using an electrostatic precipitator to control sintering emissions and a baghouse to control the combined emissions from the blast and reverberatory furnaces. Little or no control of dust emissions from the storage piles has been attempted.

Prior to discharge to the precipitator, the gases are cooled and conditioned by water sprays in the flue system. The electrostatic precipitator was installed in 1927 and has a reported collection efficiency of 97 percent. That efficiency would appear to be quite high, however, considering its installation date; the actual collection efficiency is estimated to be 90 to 92 percent. When sintering at a rate of 1000 tons per day, the lower efficiency would increase dust emissions from 800 pounds per day to approximately 2700 pounds per day, or a three-fold increase in emissions. The opacity of the precipitator discharge is difficult to determine due to the entrained water vapor, but at one point in the plant inspection the sintering operation was shut down and restarted without water being added to the gas stream. An opacity of 30 to 35 percent was observed for approximately 20 minutes before the addition of water vapor resulted in an opacity of 100 percent.

Effluents from the blast and reverberatory furnaces are combined and cooled by radiation in a long flue prior to discharge to the baghouse. The baghouse was installed in 1918 and has a reported collection efficiency of 99 percent. No visible emissions were noted at the baghouse stacks except when the bags were periodically rapped, which resulted in an opacity of 15 percent.

Techniques are available to reduce particulate emissions from the sintering operation. The precipitator can be replaced with a new unit capable of 99 percent reduction, or a baghouse can be used to give maximum collection efficiency. If a process is employed to convert the SO_2 in the gas stream to sulfuric acid or sulfur, increased particulate collection efficiency will be required to avoid fouling of converters.

Particulate emissions from the yard storage of concentrates can be reduced by enclosing the storage area and maintaining a moisture content sufficient to eliminate the formation of dust. The scrubbing of dilute SO_2 gas streams will also reduce particulate emissions by approximately 90 percent, which indicates that streams treated in this manner will require further treatment for dust removal.

SLAG PROCESSING – ANACONDA COMPANY

Process Description

The Anaconda Company operates a slag-processing plant that is charged with slag from the nearby lead smelter of American Smelting and Refining

Company. The charge contains 15 to 18 percent zinc and 1.5 percent lead. Approximately 100 tons per day of product is recovered, which consists of 91 percent of the zinc and virtually all of the lead in the charge stock. The mixture of zinc and lead is recovered in a baghouse in the oxide form after volatilization and cooling. Figure 10-2 is a simplified flow diagram for the slag-processing plant.

Fuming Furnace Charge

Both molten slag received directly from ASARCO and cold slag from storage are charged to the fuming furnace along with pulverized coal, which is used as fuel to heat the charge to approximately 2200° F. The coal and blast air enter the water-jacketed furnace near the bottom of the slag bath. The zinc and lead are vaporized and subsequently oxidized, and are drawn from the furnace through a flue and cooling system by an induced-draft fan before recovery. After the oxides have been formed and removed from the furnace, the slag is removed for disposal in a dump.

Cooling and Recovery System

The oxides and other gases are cooled first by water sprays in balloon flues to 1000° F and then by radiation and convection in U-shaped tubes to approximately 300° F. If additional cooling is required, it is done by air dilution to a final temperature of approximatley 250° F before discharge to the baghouse. After recovery, the fume is loaded into open gondola-type hopper cars for shipment to a zinc refinery for further processing.

Emissions

The fuming operation emits sulfur dioxide and particulates at the charging door of the furnace and through stacks at the baghouse. In addition, particulates are emitted through a stack at the coal-pulverizing mill, and particulates and SO_2 are released when the residue slag is dumped.

Sulfur Dioxide

When charging 645 tons per day of molten slag and 55 tons per day of cold slag along with 140 tons per day of pulverized coal, the SO_2 emissions from the fuming furnace are estimated to be approximately 13 tons per day. This offgas passes through a baghouse prior to discharge to the atmosphere. In addition, an undetermined amount of SO_2 is emitted when the slag is charged to the furnace.

Additional SO_2 emissions occur at the slag dump when the residue slag is dumped; no estimate of the quantity of such emissions has been made, however, due to lack of data.

Particulates

When molten slag is charged to the fuming furnace, copious emissions of white fumes are emitted at the charging door. These emissions occur for

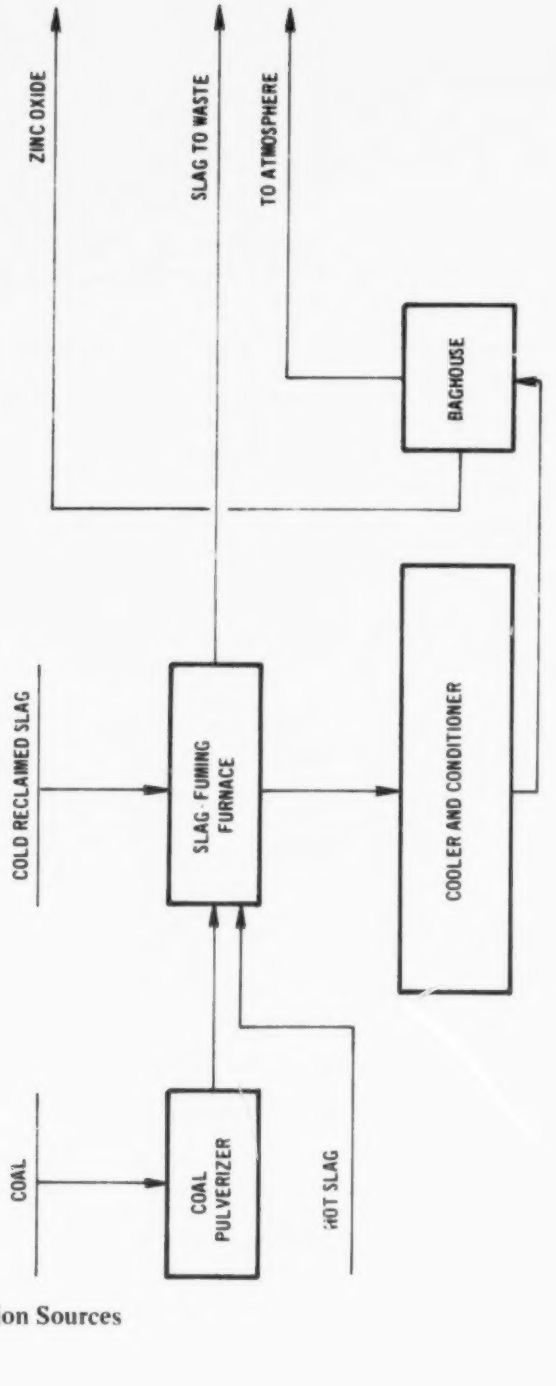

COAL
COAL PULVERIZER
HOT SLAG
COLD RECLAIMED SLAG
SLAG-FUMING FURNACE
COOLER AND CONDITIONER
BAGHOUSE
ZINC OXIDE
SLAG TO WASTE
TO ATMOSPHERE

Figure 10-2. Simplified flow diagram for slag-processing plant.

approximately 5 minutes during each addition of slag. It is estimated that the fume consists mainly of the oxides of zinc, lead, and possibly cadmium; although no estimate of the quantity has been made due to lack of data, it is believed to be considerable.

The oxide fume formed by the operation is collected by a baghouse that is estimated to have a relatively high collection efficiency. For this reason it is estimated that the particulate emissions are negligible from this portion of the source.

Particulates are emitted when the residue slag is dumped. The exact amount is not known, but it is estimated that it is in excess of 0.5 percent of the slag or over 1 ton per day.

Particulates are also emitted at the coal-pulverizing mill. The mill discharges through a mechanical collector and then to the atmosphere via a stack. The discharge has been noted to be of number four Ringelmann or greater, thus indicating a possibly significant but undetermined emission rate.

Plant Effluent

Both process and cooling waters from the facility are held in ponds for recirculation, with no discharges into Prickly Pear Creek or any other portion of the Valley's drainage system.

Air Pollution Control

Sulfur Dioxide

No attempt has been made to control the SO_2 emissions from the fuming operation or the dumping of residue slag. After passing through a bag filter for particulate removal, the gases from the furnace are discharged to the atmosphere through five 100-foot stacks. At a uniform emission rate, the SO_2 concentration is approximately 3 percent. Because the emission rate is greater during the initial phase of the 2-hour cycle, it is estimated that the maximum emission rate might be twice the uniform rate.

Emission control techniques are available that can substantially reduce the SO_2 emissions. The selection of a technique to control the emissions will depend upon such factors as the required degree of control and the economic, social, and political ramifications of control. Possible control techniques that could be employed are sulfuric acid production and effluent cleaning.

If required, it is possible to design a sulfuric acid plant to operate on low SO_2 concentrations in the feed stream, similar to those encountered in the fuming operation, but economically it would be very unattractive.

The most economical technique for control of SO_2 emissions from the fuming operation would probably be the use of a scrubber with no by-product recovery. The most economical scrubbing medium would be a slurry of pulverized limestone, $CaCO_3$. Hydrated lime, $Ca(OH)_2$, would be more efficient, but would be more expensive. An efficiency of 80 percent can be achieved using limestone, while an efficiency of 90 percent can be expected if hydrated lime with the same circulation rate is employed. The scrubber would be installed downstream from the baghouse and would scrub the gases prior to discharge through a new stack. The major disadvantage of this system would arise from treatment and disposal problems with the spent scrubbing solution. The cost and feasibility of solution treatment may well offset the economic advantages over sulfuric acid production if large-scale treatment is required.

The SO_2 and dust and fume emissions from the slag-dumping operation could be eliminated by the use of a granulating-type operation. The molten residue slag would be quenched by a water stream inside an enclosure. The effluent gases would then be vented to the proposed limestone scrubber to remove particulates, fumes, and SO_2. Even if a scrubber were not used on the fuming furnace effluent, it is quite possible that a small scrubber could be employed with a much smaller circulation rate, thus reducing the spent-solution disposal problem.

Particulates

The recovery and control of particulates from the fuming operation are accomplished by a baghouse that was installed when the plant was built in 1927; the baghouse was enlarged to its present capacity in 1957. The baghouse now contains 725 Dacron bags and has an unknown but apparently high collection efficiency that results in negligible particulate emissions.

To control particulate emissions during the fuming-furnace charging cycle, a hood and duct exhaust system should be employed. The hood would need to be either water cooled or lined with a refractory material. The fumes could be vented to the existing baghouse if the zinc and lead values are to be recovered. The increased volume to the baghouse could be counter-balanced by decreasing the amount of dilution air required. Since a considerable amount of ambient air would be drawn into the duct system at the hood, the present temeprature might be maintained without adding dilution air. If additional cooling is still required, this cooling capacity would have to be installed. If a scrubber is used to control SO_2 from the fuming operation, these emissions could be vented to it if the lead and zinc oxides present are not to be recovered. It is believed that a properly designed scrubber would be capable of handling particulate as well as SO_2 emissions.

As mentioned previously, particulate as well as SO_2 emissions from the dumping of residue slag can be controlled by employing a granulating operation.

The coal-pulverizing operation generates a considerable amount of particulate matter. This discharge previously was passed through a mechanical collector and discharged to the atmosphere. To reduce the excessive emissions, a baghouse was scheduled to be installed in the spring of 1970.

PAINT PIGMENT PRODUCTION – AMERICAN CHEMET CORPORATION

Process Description

American Chemet Corporation operates a paint pigment facility and produces leaded zinc oxide, lead-free zinc oxide, cupric oxide, and cuprous oxide. Figure 10-3 is a simplified flow diagram of the pigment plant.

Leaded Zinc Oxide

A white pigment for outdoor paint is made from zinc oxide obtained from the Anaconda Company. The oxide is heated with natural gas in rotary kilns to remove traces of coal and to react any sulfur present with the lead oxide to form lead sulfate, the entire process being for the purpose of making the pigment as white as possible. Exhaust gases from the kilns pass through two cyclones in series before being cooled to 180° F by the addition of dilution air. The daily production is approximately 15 tons; all the gases pass through a baghouse prior to discharge to the atmosphere through a 30-foot stack.

The pigment is screened to remove oversized particles, and the fines are fed to a No. 3 TH Micropulverizer to obtain material that is 99.9 percent finer than a No. 325 screen. The material is then packed into bags, and the dust-laden gases pass through a fabric filter before being discharged to the atmosphere.

Lead-Free Zinc Oxide

Another pigment is made from zinc oxide obtained from the Anaconda facility at Great Falls, Montana. The crude zinc oxide is milled to approximately 170 mesh before being packed into bags. The maximum daily production is about 100 tons. All dust generated passes through high-efficiency cyclones and a baghouse before being discharged to the atmosphere.

Copper Oxides

Crude cupric oxide is obtained from the Anaconda Company and the Kennecott Copper Corporation. The cupric oxide pigment is made by milling, and the cuprous oxide pigment is made by the reduction of cupric oxide in a closed retort. The cuprous oxide can be used to make two different pigments. It is milled as is, or it is blended with cupric oxide and then milled and packed into bags to produce two different pigments. The daily production of all copper pigments is approximately 150 tons; all dust generated during the operation passes through high-efficiency cyclones and fabric filters before discharge to the atmosphere.

Emissions and Air Pollution Control

The pigments operations emit sulfur dioxide and particulates in relatively minor amounts. Particulates probably contain small amounts of zinc, lead, and copper, whereas the amount of the SO_2 discharged is insignificant. No corrective

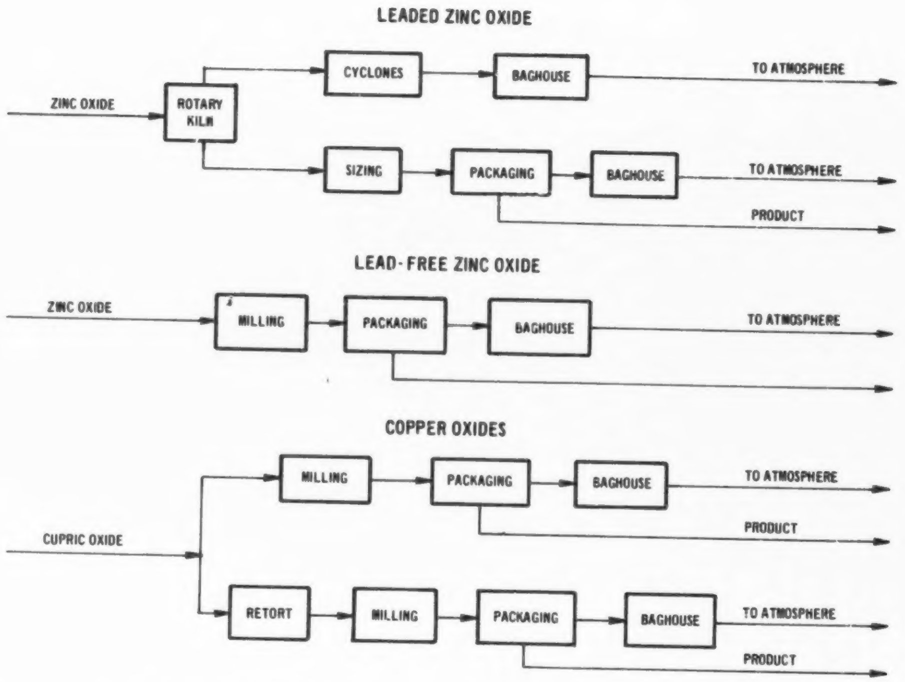

LEADED ZINC OXIDE
ZINC OXIDE
ROTARY KILN
CYCLONES
BAGHOUSE
TO ATMOSPHERE
SIZING
PACKAGING
BAGHOUSE
TO ATMOSPHERE
PRODUCT
LEAD-FREE ZINC OXIDE
ZINC OXIDE
MILLING
PACKAGING
BAGHOUSE
TO ATMOSPHERE
COPPER OXIDES
CUPRIC OXIDE
MILLING
PACKAGING
BAGHOUSE
TO ATMOSPHERE
PRODUCT
RETORT
MILLING
PACKAGING
BAGHOUSE
TO ATMOSPHERE
PRODUCT

Figure 10-3. Simplified flow diagram for pigment plant.

action or modification of existing air pollution control equipment appears necessary as long as the equipment is properly maintained and the present production output is not drastically increased.

Particulates

The gases from the kilns used in the production of leaded zinc oxide pass through two cyclones in series and then through a baghouse after the temperature has been reduced by the addition of dilution air. The gases from the production of lead-free zinc oxide also discharge to the atmosphere after passing through high-efficiency clyclones and a baghouse. With collection efficiencies greater than 99 percent, the total dust loss to the atmosphere has been reported to be approximately 30 pounds per day.

Particulates are also discharged from the production of copper oxides. Gases from these operations pass through cyclones and two baghouses prior to discharge to the atmosphere. With collection efficiencies of 99 percent being reported, a maximum of 10 pounds per day is reportedly discharged.

11. METEOROLOGY
AND
SOURCE-RECEPTOR RELATIONSHIPS

Paul Humphrey

ENVIRONMENTAL PROTECTION AGENCY
National Environmental Research Center

AIR MOVEMENT

Wind direction and speed are important factors in the transport of air pollutants from source to receptor. By definition, air moves *from* the direction that determines the name of the wind. Therefore, a *west* wind blowing across a source of pollution will transport pollutants to the east. Also, concentrations of air pollutants downwind from a source are normally inversely related to wind speed. In the bowl-like Helena Valley, very low wind speeds may be associated with a stagnation condition, whereas higher speeds ventilate the Valley, clearing out any accumulation of air pollution that might be present

Wind Stations

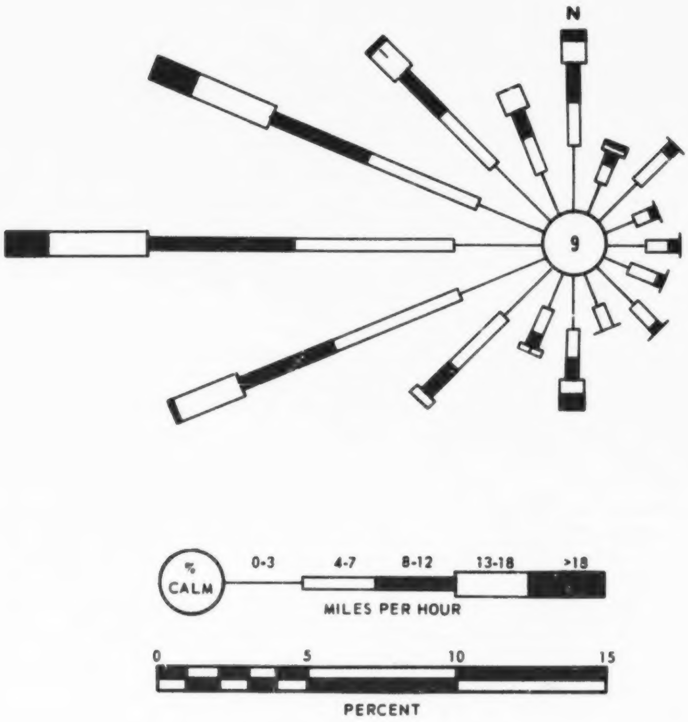
Prior to 1961, the wind sensors operated by the National Weather Service Station at the Helena Municipal Airport were located on the roof of the control tower at a height of 44 feet above ground level. In 1961 the sensors were moved to a 20-foot mast located near the intersections of the runways, approximately 1600 feet from the original location. The change in exposure has not introduced any noticeable change in the data obtained. The National Air Pollution Control Administration* (NAPCA) installed two wind systems (Climet C-26) that were operated during the study period. One was located on a 24-foot tower that was set on an 8-foot platform on the roof of the three-story Cogwell Building in Helena. The sensor itself was mounted about 68 feet above ground level. The other site was on Prickly Pear Street in the eastern part of East Helena, where the sensor was exposed on a towertop at 48 feet above ground level in an open field. The stations were of the continously recording type. Wind data were obtained visually from the charts by the "equal area" method over 1-hour periods.

---

*Now the Office of Air Programs of the Environmental Protection Agency.

Wind Direction

The annual wind rose, Figure 11-1, shows that the most frequent wind direction at the Helena Municipal Airport is from the west.[1] The annual occurrence of west wind is reported to be 18 percent; west-northwest and west-southwest winds are reported to be 14 and 13 percent, respectively; the summation within these three sectors is 45 percent of the total winds. Easterly winds occur least frequently. In general, the wind rose for Helena is symmetrical about the east-west axis. Calm is observed 9 percent of the year.



November 1949 - October 1954.

Figure 11-1. Annual wind rose, Helena, Montana.[1]

Wind Speed

Monthly mean windspeeds for the years 1937 to 1963 for Helena, Montana, (Weather Service Airport Station) are given in Table 11-1. Compared with other areas in the United States, the Helena Valley has a relatively high frequency of light winds.

Table 11-1. MONTHLY MEAN WINDSPEEDS, HELENA, MONTANA, 1937 to 1963

(mph)

Month	Speed	Month	Speed
January	6.9	July	7.9
February	7.8	August	7.7
March	8.6	September	7.7
April	9.3	October	7.4
May	9.1	November	7.2
June	8.6	December	7.0

ATMOSPHERIC STABILITY AND TEMPERATURE INVERSIONS

In simple terms, the stability of the atmosphere is its tendency to resist or enhance vertical motion or, alternately, to suppress or augment existing turbulence.[2] The atmosphere is said to have "neutral" stability when the temperature lapse rate is essentially *dry adiabatic* (5.4° F per 1000 feet). If the temperature decrease with elevation is greater than that, the condition is *unstable;* if the temperature decreases at a lower rate, the condition is *stable.* A temperature inversion exists in a layer of air when the temperature increases with elevation. Within an inversion layer, however, the atmosphere can be very stable; this condition promotes poor dispersion of air pollutants.

Air that is raised or lowered changes temperature at the dry adiabatic rate while unsaturated. Therefore, a small volume of air that is given a vertical motion under unstable conditions will be accelerated upward or downward because of its density with respect to its surroundings. On the other hand, a small volume of air that is displaced vertically under stable conditions will tend to return to its original level.

Figure 11-2 shows typical temperature soundings obtained at various times during a 24-hour period with clear skies and light winds.[3] These vertical temperature profiles were observed at the AEC National Reactor Testing Station, Idaho, an intermountain desert valley location. Under similar meteorological conditions, nearly identical profiles can be observed in the Helena Valley. With the absence of clouds and with light winds, the cooling of the ground during the night results in the creation of a strong temperature inversion. Strong heating of the ground during the day by solar radiation results in a rapid decrease of temperature with height.

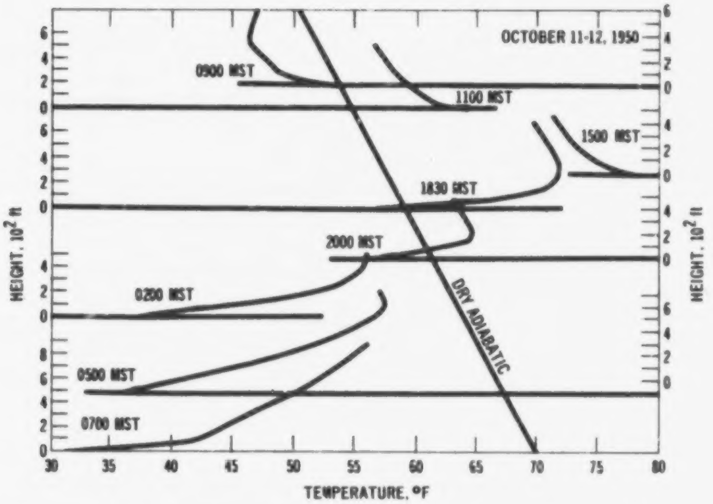


Figure 11-2. Temperature soundings on day with clear skies and light winds.[3]

The formation, deepening, and destruction of the surface-based inversion layer can be seen in Figure 11-2. The shallow temperature inversion layer observed at 1830 MST became more intense and deepened until sunrise, about 0700 MST. By 0900 MST, 2 hours later, the inversion was destroyed from the surface up to an elevation of about 600 feet.

Windy conditions thoroughly mix air and tend to cause a condition of neutral stability. Clouds exert a thermostatic control, reflecting the incoming shortwave solar radiation and absorbing and reradiating the outgoing longwave terrestial radiation back to the ground. Night or day, strong winds and cloudy skies work together to create and maintain neutral stability, thereby preventing either temperature inversions or unstable temperature profiles.

A fresh layer of snow reflects over 80 percent of the heat from the sun and readily loses heat from its surface.[4] Other conditions being the same, minimum temperatures are lowest and inversions most intense over a snow surface. Under such conditions, the temperature difference between the surface and the top of the inversion may be as much as 40° F.

The Helena Valley is ideal for the formation of strong and persistent temperature inversions. The factors favoring the radiation of heat are the altitude, relative dryness, long winter nights, lack of cloudiness, and frequent snow cover during winter months. Inversions are also favored both by the sheltering effects of surrounding mountains, which produce low wind speeds and calms, and by the cold air that drains at night into the Valley from the mountain slopes.

There may be considerable day-to-day variation in the maximum thickness of the nocturnal inversion. The height of the top of the inversion layer may vary from a few hundred feet to over 5000 feet above the ground.

Due to the moderating influence of the Pacific Ocean, most of the air masses flowing over this area are usually warmer during winter and cooler in summer than air masses at a similar latitude in the more continental climate farther east of the Divide. The Big Belt Mountains act as a barrier and keep shallow, but intensely cold, winter air masses that push southward from Canada over the Great Plains from entering the Helena Valley. Occasionally, however, the very cold air of continental origin is sufficiently deep to either spill over the mountain ridges or enter the Helena Valley from the north via the valley of the Missouri River. Afterwards the cold air is walled in by the surrounding mountains, and the Helena Valley can experience a period of low temperatures lasting a week or longer. With this condition, there is a layer of warmer air above the cold air or there is, in effect, a persistent temperature inversion aloft that can act as a lid and trap air pollution below it.

Typical winter and summer temperature profiles[5] from heights of up to 2000 meters at the AEC National Reactor Testing Station, Idaho, are shown in Figure 11-3. The morning (0858 MST) and afternoon (1407 MST) temperature

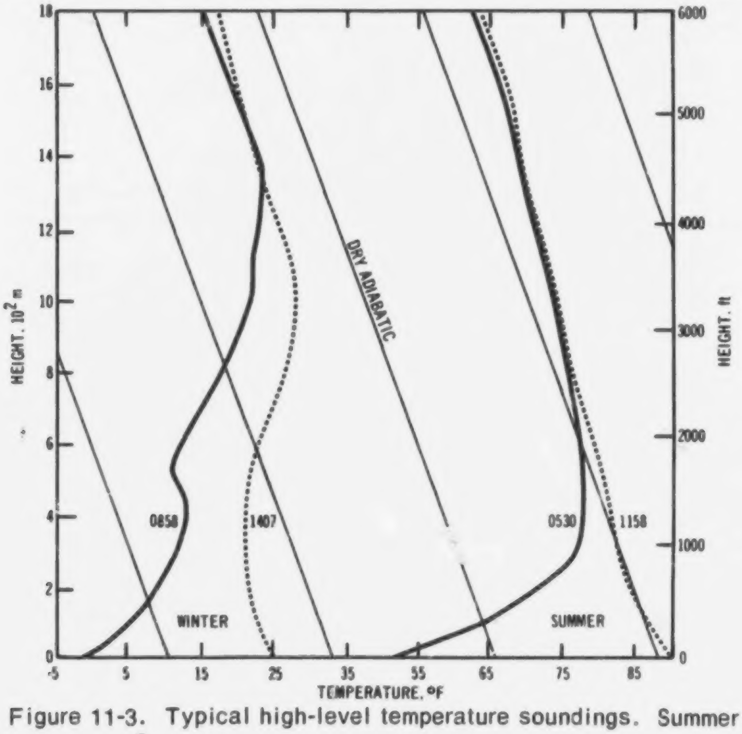


Figure 11-3. Typical high-level temperature soundings. Summer and Winter.[5]

profiles in winter are excellent indicators of the dissipation of the nocturnal inversion in the lower levels by surface heating with an inversion at higher levels being maintained throughout the day. In summer there is usually sufficient heating to completely eliminate inversion conditions, as shown by the early morning (0530 MST) and the late morning (1158 MST) temperature profiles.

Although temperature inversions have never been routinely measured in the Helena Valley, the seasonal and annual frequency of inversion conditions can be interpolated from maps prepared by Hosler.[6] The values obtained from these maps and given in Table 11-2 would be expected to be conservative – somewhat less than the true values – because the Valley effects have been somewhat smoothed out.

Table 11-2. SEASONAL AND ANNUAL INVERSION FREQUENCY AT HELENA, MONTANA[a]

(% of total hours)

Season	Frequency
Winter	47
Spring	32
Summer	32
Fall	45
Annual	38

[a] Inversions and/or isothermal conditions, based below 500 feet above station elevations.

Data in Table 11-3, collected at a 250-foot meteorological tower located at the Idaho Reactor Testing Station, show a higher frequency of inversion conditions and may be more representative of the Helena Valley.

Table 11-3 SEASONAL AND ANNUAL INVERSION FREQUENCY AT IDAHO FALLS, IDAHO[a]

(% of total hours)

Season	Frequency
Winter	52
Spring	37
Summer	45
Fall	57
Annual	48

[a] For this table, an inversion is defined as a condition wherein the temperature at the 250-foot level is greater than at the 50-foot level.

The greatest number of hours of inversion occurs in the cold half of the year. Spring is relatively cloudy and windy, but summer has more hours of inversion than might be expected because of a high frequency of clear, or nearly clear, nights.

Stability of the atmosphere can be estimated from surface observations by the method of Turner,[7] which was employed with National Weather Service observations at the Helena Airport for the years 1962 through 1964 to estimate the percent occurrence of the six categories tabulated in Table 11-4.

Table 11-4. STABILITY IN HELENA VALLEY[4]

	Monthly occurrence, %				
Stability class	Jan	Apr	July	Oct	Annual
Very unstable . . . . (A)	0	0	3	0	1
Unstable . . . . (B)	2	10	19	8	10
Slightly unstable . . . . (C)	7	9	14	10	10
Neutral . . . . (D)	56	56	29	36	44
Stable . . . . (E)	15	11	15	17	14
Very stable . . . . (F)	20	15	20	29	21

POTENTIAL AIR POLLUTION EPISODE DAYS

A mixing layer that has its base at the earth's surface is caused by turbulent motions created by the mechanical flow of air over and around obstacles and by thermally produced air currents. Mixing erodes and can destroy an inversion layer, because thorough mixing produces a condition in which temperature decreases with height. The depth of the mixing layer usually varies diurnally and can range from near zero during the night to a maximum depth during the afternoon.

At locations such as Helena, where radiosonde observations have never been made, mixing depths have been estimated by interpolation of data from the nearest radiosonde stations with some consideration being given to topographic differences.

A potential air pollution episode is defined here as a situation wherein precipitation lasts at least 2 consecutive days, mixing height (Figure 11-4) is equal to or less than 1500 meters (4921 feet), and average wind speed through the layer is equal to or less than 4.0 meters per second (8.9 mph). By this definition the total number of potential episode days during 5 years for Helena is estimated to be approximately 25, a low number in relation to many areas. The Great Salt Lake Valley in Utah and the Central Valley in California have ten times as many episode days as Helena. The threat of a buildup of concentrations over a period of 2 days or more is relatively small in the Helena Valley.

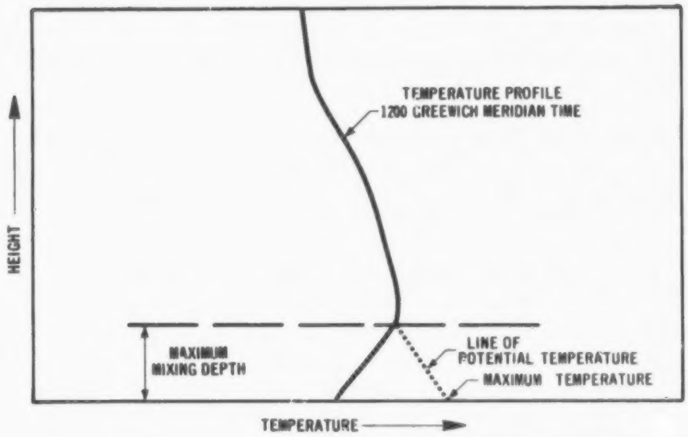


Figure 11-4. Graphical determination of afternoon (maximum) mixing depth. The slope of the line of potential temperature corresponds to the adiabatic lapse rate, which is 5.4°F per 1000 ft of elevation, approximately.

PRECIPITATION AMOUNTS AND WIND SPEEDS AFFECTING THE REPRESENTATIVENESS OF THE STUDY PERIOD

February, March, April, and May of 1969 had somewhat less than normal amounts of precipitation. The amount of water available for spring runoff and soil moisture, however, is likely to have been greater than usual in 1969 because of the heavy January snow cover. The total precipitation for January was 2.78 inches, whereas the normal for the month is 0.47 inch.

As shown in Table 11-5, the months of June, July, and October were wetter than normal, whereas August and September were somewhat drier. Only October had more than the normal number of days with rain. Average monthly wind speeds were exactly normal, or near normal, except for September, which had significantly lower wind speeds.

Concentrations of air pollutants are expected to be less on rainy days, or when wind speeds are greater than normal. For example, June 24 to 26, a stormy period during which 2.21 inches of precipitation fell, was a period when meteorological conditions would have caused unusually low concentrations of air pollution at measuring stations.

Assuming that emission rates of air pollutants were constant, wind and precipitation conditions would have caused average air quality values that were lower than normal for the months of June, July, and October, but somewhat higher than normal values during September. Average concentrations for the entire study period would have been somewhat lower than the normal, primarily because of the precipitation periods in October.

Table 11-5. NORMAL AND ACTUAL MONTHLY WINDSPEED, PRECIPITATION AMOUNTS, AND NUMBER OF DAYS WITH PRECIPITATION, HELENA, MONTANA

		Jun	July	Aug	Sept	Oct	Mean
Wind speed, mph	Normal	8.6	7.9	7.7	7.7	7.4	7.9
	1969	7.9	7.9	7.7	6.6	7.9	7.6
	Difference	-0.7	0.0	0.0	-1.1	0.5	-0.3
Precipitation, in.	Normal	2.23	1.03	0.89	0.95	0.66	1.15
	1969	3.50	1.77	0.38	0.33	1.06	1.41
	Difference	1.27	0.74	-0.51	-0.62	0.40	0.26
Days with precipitation 0.01 inch or more	Normal	13	7	8	7	6	8.2
	1969	11	6	1	5	11	6.8
	Difference	-2	-1	-7	-2	5	-1.4

DIFFUSION ESTIMATES OF MEAN SHORT-TERM SO_2 CONCENTRATIONS

The three most significant sources of sulfur dioxide were considered for diffusion estimates of mean short-term concentrations in the Helena Valley. These sources were the 400-foot ASARCO stack (without and with fan and heater), the ASARCO baghouse, and the Anaconda baghouse. A fan and heater were installed at the ASARCO stack in the spring of 1970 to increase plume height and thereby decrease ground concentrations.

The values of the parameters used in calculating the plume heights from these sources are shown in Table 11-6. All rates of emissions are based upon a charging rate of 1000 tons of ore per day to the ASARCO sintering plant.

Table 11-6. THREE MOST SIGNIFICANT SULFUR DIOXIDE SOURCES

Sources	Stack height, ft	Stack diameter, ft	Stack gas velocity, m/sec	Stack gas temperature, °F	SO_2 emissions, tons/day
ASARCO stack (no fan or heater)	400	16	4.8	140	263
ASARCO stack (fan and heater)	400	16	8.2	260	263
ASARCO baghouse (3 stacks)	117	(Square, side 8 ft)	4.7	150	25
Anaconda baghouse (5 stacks)		(Square, side 12 ft)	2.1	250	11.2

[a] Maximum value; includes all ASARCO emissions not from 400-foot stack.

The SO_2 emission rate for the ASARCO baghouse, 25 tons per day, was estimated from a mass-product balance. A second estimate, which assumed more sulfur in slag, was 11.8 tons per day. In a letter dated May 8, 1970, the ASARCO plant manager, Mr. S. M. Lane, stated that the correct figure was 1.8 tons per day from the ASARCO baghouse. There are also some emissions of SO_2 that occur as leakage from buildings and in the handling of slag. Therefore, the emission rate of 25 tons per day is considered to be a maximum value. It accounts for all ASARCO emissions not from the 400-foot stack.

Both the distance from the source to the point of maximum short-term concentration and the concentration at that point are functions of the meteorological conditions, stack design, and physical properties of the emissions. Estimates of the short-term concentrations at East Helena Park emanating from the 400-foot stack (with and without fan and heater) and the two baghouses are presented in Table 11-7. The values are estimates of the mean concentrations for

Table 11-7. SHORT-TERM CONCENTRATIONS OF SO_2 AT EAST HELENA PARK

Stability	Wind speed mph	Source	SO_2, ppm
Very unstable	4.5	a	2.27
		b	1.70
		c	0.37
		d	0.85
Moderately unstable	4.5	a	1.81
		b	0.07
		c	1.45
		d	0.75
Slightly unstable	6.7	a	0.26
		b	<0.01
		c	1.71
		d	0.72
Neutral	13.4	a	<0.01
		b	<0.01
		c	1.09
		d	0.21
Slightly stable	6.7	a	<0.01
		b	<0.01
		c	0.79
		d	<0.01
Stable	6.7	a	<0.01
		b	<0.01
		c	0.04
		d	<0.01

[a] ASARCO stack (no fan or heater); 0.56 mile from East Helena Park.
[b] ASARCO stack (fan and heater); 0.56 mile from East Helena Park.
[c] ASARCO baghouse; 0.5 mile from East Helena Park.
[d] Anaconda baghouse; 0.25 mile from East Helena Park.

time periods up to about 1 hour for the given conditions. The emission rates are based upon materials-balance analysis of the individual plants, and all SO_2 generated by the processes is assumed to be emitted from the stacks.

Mean, short-term concentrations at the point of maximum potential impact from the sources are shown, along with the distance to that point, in Table 11-8. These values can occur in any direction from the respective sources, depending upon wind direction.

Table 11-8. ESTIMATED MAXIMUM GROUND-LEVEL CENTERLINE CONCENTRATIONS OF SO_2 AND DISTANCE FROM SOURCE FOR SELECTED METEOROLOGICAL CONDITIONS

	Wind speed,	ASARCO (without fan and heater)		ASARCO (with fan and heater)		ASARCO baghouse		Anaconda baghouse	
Stability[a]	mph	ppm	miles	ppm	miles	ppm	miles	ppm	miles
A	4.5	4.54	0.4	1.87	0.5	2.62	0.2	0.90	0.2
B	4.5	3.40	0.7	1.08	1.2	2.53	0.2	0.87	0.3
C	6.7	1.91	1.3	0.92	1.9	2.15	0.3	0.88	0.4
D	13.4	0.71	3.1	0.40	4.3	1.31	0.5	0.62	0.5
E	6.7	0.57	8.0	0.24	14.0	1.78	0.9	0.80	0.9
F	6.7	0.17	31.0	0.07	43.0	1.25	1.7	0.56	1.7

[a] A = very unstable; B = moderately unstable; C = slightly unstable; D = neutral; E = slightly stable; and F = stable.

Downwash, a phenomenon that sometimes causes high ground concentrations close to some elevated sources, is created by turbulence induced by nearby objects such as buildings, trees, and bluffs. This phenomenon seems likely to occur with the baghouse sources because of the relatively low stacks on relatively large buildings. Computations of the resulting concentrations of SO_2 for East Helena Park are shown in Table 11-9. It is estimated that downwash from these two sources can cause ground-level concentrations of SO_2 in excess of 8 ppm in East Helena.

Fumigation conditions, as previously defined, can result in relatively high ground-level concentrations at greater distances than those shown in Table 11-8. For example, the estimated ground-level, centerline concentration under conditions of inversion breakup (fumigation) at 6 miles from the source is 1.7 ppm of sulfur dioxide, assuming that the source is the 400-foot ASARCO stack (with fan and heater) and the rate of emission of sulfur dioxide (2761 grams per second) is based upon 1000 tons per day charging rate to the sintering plant. The windspeed is assumed to be 4.5 miles per hour.

Table 11-9. CONCENTRATIONS OF SO_2 AT EAST HELENA PARK DURING AERODYNAMIC DOWNWASH FROM SOURCE BUILDINGS WITH WINDSPEED OF 8 MPH

Stability	Source	SO_2, ppm
Moderately unstable	a	0.75
	b	1.16
Slightly unstable	a	1.68
	b	2.22
Neutral	a	3.59
	b	3.37
Slightly stable	a	5.09
	b	3.71

[a] ASARCO baghouse; distance – 0.5 mile.
[b] Anaconda baghouse; distance – 0.25 mile.

DIFFUSION ESTIMATES OF MEAN LONG-TERM SO_2 CONCENTRATIONS

The basic diffusion model used for mean long-term concentrations is the Martin-Tikvart model.[8] The ground elevations at the sources and receptors are considered. Where the receptor is higher than the ground level of the source, the difference in elevation is subtracted from the plume height. It is thus possible that a substantial plume height could be reduced to zero by a difference in ground elevation. If the ground elevation at the source is higher than that at the receptor, the difference is added to the plume height.

The mean afternoon mixing depth used as input to the model was 1617 meters (5300 feet). For the most unstable situations, this was increased by 50 percent. When the base of a stable layer is lower than the plume rise, the plume penetrates into the stable layer; in such situations, the model nullifies any contribution from an elevated source to ground-level pollution. This is assumed to have occured 20 and 10 percent of the time during slightly stable and very stable conditions, respectively. The assumptions are made that the wind flow over the area is homogeneous and identical to that observed hourly at the National Weather Service Forecast Office, Helena Municipal Airport, and that downwash is negligible.

All computations are based upon a charging rate of 1000 tons per day to the sintering plant and continuous processing of the by-products.

Four different maps of ground concentrations were prepared using the diffusion model (Figures 11-5 through 11-8). The first of these maps (Figure 11-5) shows that the estimated pattern for the study period, June through October, compares favorably with the observed pattern. The estimated concentrations are slightly greater than those observed because two of the plants were

REFERENCES FOR CHAPTER 11

1. U.S. Department of Commerce, National Weather Service Forecast Office. Summary of Hourly Observations. Climatography of the United States No. 30-24.

2. Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. The American Society of Mechanical Engineers, United Engineering Center, 345 East 47 Street, New York, New York 10017. p. 7.

3. U.S. Department of Commerce. Atomic Energy Commission. Meteorology and Atomic Energy. AECU 3066, p. 28. 1955 (out of print).

4. Byers, H. R. General Meteorology. McGraw-Hill Book Company, Inc. New York, 1959. p. 23.

5. Yanskey, G. R., E. H. Markee, Jr., and A. P. Richter. Climatology of the National Reactor Testing Station - IDO - 12048. Air Resources Field Research Office, National Reactor Testing Station, ESSA, Idaho Falls, Idaho, January 1966.

6. Holser, C. R. Low-Level Inversion Frequency in the Contiguous United States. Monthly Weather Review, *89*:319-339. September 1961.

7. Turner, D. Bruce. A Diffusion Model for an Urban Area. Journal of Applied Meteorology, *3*:83-91. February 1964.

8. Martin, Delance O. and Joseph A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Paper presented at the 61st annual meeting of the Air Pollution Control Association, St. Paul, Minnesota. June 1968.

SUMMARY

Because the atmosphere is the medium by which air pollutants are transported from the emission source, for a given source strength, its action governs the duration and frequency of receptor exposure, and the concentration to which any receptor will be exposed. Wind, stability, temperature inversion conditions, and types of plume behavior are described so that they can be related to observed or estimated concentrations of air pollutants.

The threat of a buildup of concentrations over a period of 2 days or more is relatively small in the Helena Valley. Potentially high concentrations of air pollution, however, can occur for shorter periods. One cause is light winds and strong temperature inversions, with associated fumigation and trapping effects. The other is instability during the daytime, which can cause a stack plume to loop and reach the ground close to the source.

Diffusion calculations were made for sulfur dioxide emissions to estimate both short- and long-term concentrations. The estimates agree with the measured sulfur dioxide levels, show the relative effect of the different emission sources, and will assist in the evaluation of the effectiveness of suggested control measures to reduce ground concentrations of sulfur dioxide.

The climatology of the Helena Valley was compared with observed conditions during the study period, June through October 1969, so that the representativeness of the study period could be estimated. It is concluded that measured air pollution concentrations are somewhat below those expected because of the above-normal amount of rain and associated windy conditions in June, July, and October.

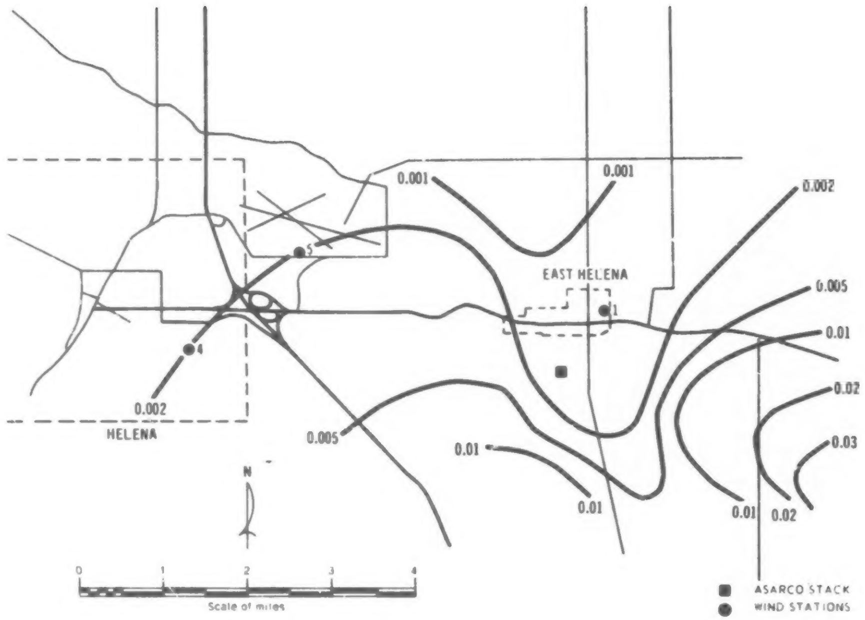

0.001
0.001
0.002
EAST HELENA
1
5
4
0.005
0.01
0.02
0.03
0.002
HELENA
0.005
0.01
0.01
0.01
0.02
N
0
1
2
3
4
Scale of miles
ASARCO STACK
WIND STATIONS

Figure 11-8. Estimated mean annual concentrations of SO_2 (ppm) from ASARCO stack with fan and heater.

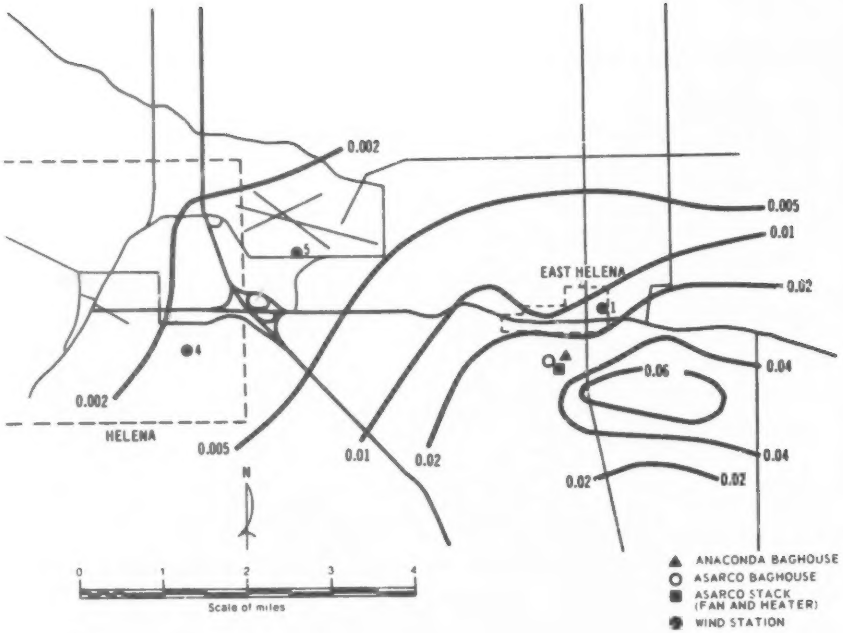

0.002
0.005
0.01
0.02
0.04
0.06
0.04
0.02
0.02
0.02
0.01
0.005
0.002
EAST HELENA
HELENA
1
4
5
N
0
1
2
3
4
Scale of miles
▲ ANACONDA BAGHOUSE
○ ASARCO BAGHOUSE
■ ASARCO STACK (FAN AND HEATER)
● WIND STATION

Figure 11-7. Estimated mean annual concentrations of SO_2 (ppm) from three sources in Helena Valley.

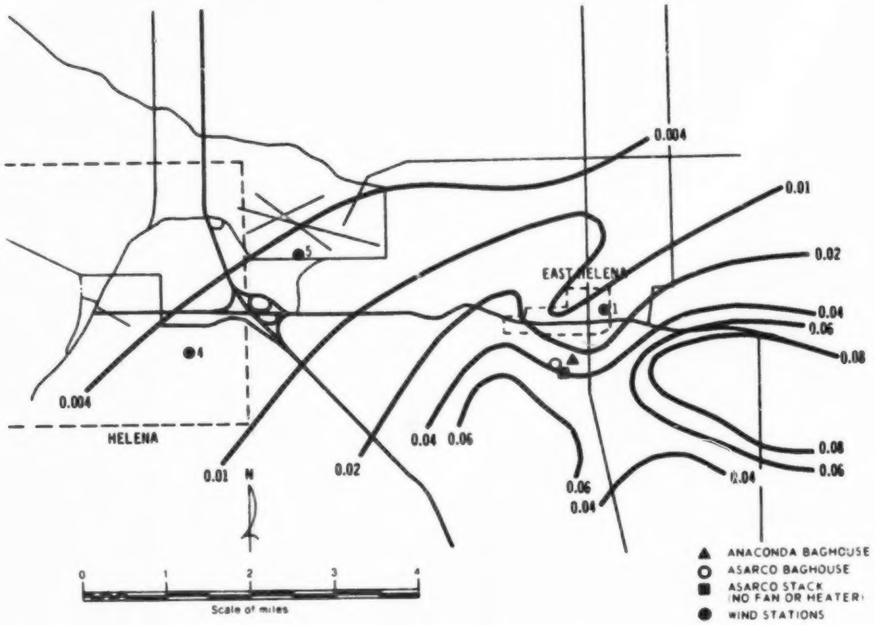

0.004
0.01
0.02
0.04
0.06
0.08
0.08
0.06
0.04
0.06
0.04
0.04 0.06
0.02
0.01
0.004
EAST HELENA
HELENA
5
4
1
N
0 1 2 3 4
Scale of miles
▲ ANACONDA BAGHOUSE
○ ASARCO BAGHOUSE
■ ASARCO STACK (NO FAN OR HEATER)
● WIND STATIONS

Figure 11-5. Estimated mean concentrations of SO_2 (ppm) from three sources in Helena Valley, June through October 1969.

not in operation at full capacity during the month of June. The estimated pattern does not show small areas of high concentration near the sources because of failure to consider downwash, building leakage, and other low-level emissions.

The second map (Figure 11-6), based on annual mean climatological data, has a pattern similar to that of the months of the study period; because of the seasonal variations in the ability of the atmosphere to dilute pollutants, however, the estimated maximum for June through October (greater than 0.08 ppm) is somewhat less than the estimated annual maximum value (in excess of 0.10 ppm). One would thus expect the observed maximum during the study period (0.04 ppm) to be lower than the annual maximum by a similar ratio, and the expected annual maximum to be approximately 0.05 ppm. The third map (Figure 11-7) shows that a 40 percent reduction in the average annual maximum value for ground-level concentrations occurs as a result of the addition of a fan and heater to the tall stack, with all sources considered. The fourth map (Figure 11-8) shows the ground pattern from the tall stack after the addition of the fan and heater. Because this pattern is significantly different from the pattern estimated to be caused by the stack and two baghouses, which more or less matches the actually observed pattern of concentrations, it is evident that low-elevation sources also are significant contributors to the observed SO_2 pollution in East Helena and vicinity.

DISPERSION OF PARTICULATE MATERIAL

The quantity and chemical compositon of airborne particles emitted by the industrial sources in East Helena are not known. The size distributions of particles, as emitted, and physical properties such as shape and density also are not known. Therefore, quantitative estimates of the distribution of particles at ground level cannot be made.

Particles are released from low-elevation industrial sources in the East Helena area as well as from the tops of stacks. The effects of low-level sources would be most severe near the source, whereas the point of maximum concentration from stack emissions occurs some distance downwind.

The baghouses and the electrostatic precipitator (ESP) favor collection of the larger particles. The particles that escape collection, either by virtue of their physical properties or by leakage before reaching the collectors, will attain a fall velocity directed toward the ground. This velocity will be greater than that of SO_2, which is assumed to be neutrally buoyant at ambient temperature. One would expect, therefore, the pattern of ground-level, airborne particulate concentrations to show areas of maximum impact closer to the sources than the SO_2 pattern.